

Public **JOURNAL OF** Transportation

■ Khaled F. Abdelghany
Ahmed F. Abdelghany
Hani S. Mahmassani
Akmal S. Abdelfatah

Modeling Bus Priority Using Intermodal Dynamic
Network Assignment-Simulation Methodology

■ Mark W. Burris
Justin R. Winn

Slugging in Houston—
Casual Carpool Passenger Characteristics

■ Robert Cervero

Office Development, Rail Transit, and Commuting Choices

■ Nor Ghani Md. Nor
Abd Rahim Md. Nor
Ahmad Zainuddin Abdullah

Predicting the Impact of Demand- and Supply-Side Measures
on Bus Ridership in Putrajaya, Malaysia

■ Robert B. Noland
Muhammad M. Ishaque

Smart Bicycles in an Urban Area:
Evaluation of a Pilot Scheme in London

■ Amer Shalaby
Jinwoo Lee
John Greenough
Stanley Hung
Michael D. Bowie

Development, Evaluation, and Selection of
Advanced Transit Signal Priority Concept Directions

Public Transportation

JOURNAL OF

Volume 9, No. 5, 2006

ISSN 1077-291X



The Journal of Public Transportation is published quarterly by

National Center for Transit Research

Center for Urban Transportation Research

University of South Florida • College of Engineering

4202 East Fowler Avenue, CUT100

Tampa, Florida 33620-5375

Phone: 813•974•3120

Fax: 813•974•5168

Email: jpt@cutr.usf.edu

Website: www.nctr.usf.edu/journal.htm

© 2006 Center for Urban Transportation Research

CONTENTS

Modeling Bus Priority Using Intermodal Dynamic Network Assignment-Simulation Methodology

Khaled F. Abdelghany, Ahmed F. Abdelghany, Hani S. Mahmassani, Akmal S. Abdelfatah 1

Slugging in Houston—Casual Carpool Passenger Characteristics

Mark W. Burris, Justin R. Winn 23

Office Development, Rail Transit, and Commuting Choices

Robert Cervero 41

Predicting the Impact of Demand- and Supply-Side Measures on Bus Ridership in Putrajaya, Malaysia

Nor Ghani Md. Nor, Abd Rahim Md. Nor, Ahmad Zainuddin Abdullah 57

Smart Bicycles in an Urban Area: Evaluation of a Pilot Scheme in London

Robert B. Noland, Muhammad M. Ishaque 71

Development, Evaluation, and Selection of Advanced Transit Signal Priority Concept Directions

Amer Shalaby, Jinwoo Lee, John Greenough, Stanley Hung, Michael D. Bowie 97

*Our troubled planet can no longer afford the luxury of pursuits
confined to an ivory tower. Scholarship has to prove its worth,
not on its own terms, but by service to the nation and the world.*

—Oscar Handlin

Modeling Bus Priority Using Intermodal Dynamic Network Assignment-Simulation Methodology

Khaled F. Abdelghany, Southern Methodist University
Ahmed F. Abdelghany, Embry-Riddle Aeronautical University
Hani S. Mahmassani, University of Maryland
Akmal S. Abdelfatah, American University of Sharjah

Abstract

This article presents a modeling framework that represents bus priority at signalized intersections in the context of its potential network-level and intermodal effects. The model incorporates bus priority within an intermodal dynamic traffic assignment-simulation model. It dynamically assigns travelers to different modes and routes in the network according to prevailing traffic conditions, which result from applying a certain network control/bus priority scheme. The model considers changes in traffic conditions as a result of (1) drivers' route choice adjustments due to changes in traffic signals settings and (2) modal shifts by travelers to take advantage of improved transit service. Three different bus priority strategies are considered: phase (green) extension, red truncation, and phase advance. A set of simulation experiments is performed to compare these strategies using two different assignment scenarios: single-mode assignment and intermodal assignment. The results of these experiments highlight the importance of considering reassignment and potential modal shifts in evaluating traffic network performance under different control schemes, especially

when these schemes are expected to affect the modal split in the network such as bus priority.

Introduction

An important operational goal for transit agencies is to maintain fast and reliable transit service for customers and to be competitive against private-car use. Over the last two decades, bus priority at signalized intersections has gained attention as a possible technique to improve transit vehicle travel time. Advances in detection devices and communication technologies as well as in signal controllers have enabled a variety of intelligent bus priority strategies. Provision of bus priority at traffic signals is a commonly available functionality of modern signal controllers. Several programs using different logic and strategies are available for implementation in conjunction with both isolated and networked controllers (Baker et al. 2002; Smith et al. 2005). Most real-time adaptive control systems for signalized networks provide priority capabilities for buses and other special vehicles (e.g., Emergency Management Vehicles) (Lowrie 1982; Sims and Finlay 1984; Longfoot 1982; Yagar 1993; Sunkari et al. 1995; Chang et al. 2003; Mirchandani and Lucas 2004). Three main bus priority strategies are widely applied: phase extension, red truncation, and phase advance. In the phase extension strategy, when a transit vehicle is detected and the phase that serves this vehicle is active, the green is extended to ensure that this vehicle crosses the intersection. If a transit vehicle is detected while the phase that serves it is not active, the vehicle waits until its phase is reactivated in the next cycle. Red truncation and phase advance strategies provide additional priority options for transit vehicles. They advance the green for the detected transit vehicles either immediately (phase advance) or after providing minimum or some reduced green (red truncation) to the other phases. The net effect is to reduce the stopping time of the transit vehicles at the intersection.

Several researchers have investigated the relative desirability, operational performance, and evaluation of bus priority strategies (Heydecker 1983; Chard and Lines 1987; Radwan and Benevell 1983; Bell 1992; Chang et al. 1995; Khasnabis et al. 1996; Garrow and Machemehl 1997; Baker et al. 2002; Chang and Ziliaskopoulos 2003; Nash 2003; Smith et al. 2005). Previous studies to evaluate different bus priority strategies have been limited in one or more of the following aspects:

- Studies and models that have considered bus priority at the network level have ignored the vehicles reassignment phenomenon that could accompany

the change in a signal timing plan. A change in signal timing due to bus priority would affect travel times along several paths in the network, resulting in some switching to shorter paths by auto drivers. While this reassignment has been well recognized in the literature for signal timing in general (Abdel-fatah and Mahmassani 1998), it has not been considered explicitly with bus priority. Evaluating bus priority in a dynamic assignment framework, which considers the vehicles reassignment phenomenon, provides a better evaluation of the long-term impacts of implemented strategies.

- The effect of bus priority on mode choice is essential to evaluate bus priority strategies comprehensively, and does not appear to be reported in the literature. Changes in auto and transit travel times due to transit priority may induce some tripmakers to shift from one mode to another. This would affect the total number of vehicles in the network and consequently change the overall network performance. Ignoring this dimension in previous studies will likely understate the benefits of bus priority.

The model described in this article incorporates bus priority at signalized intersections in the context of its potential intermodal network-level effects. The model considers changes in traffic conditions as a result of (1) drivers' route choice adjustments due to changes in traffic signals settings and (2) modal shifts by travelers to take advantage of improved transit service. The methodology overcomes the key limitations of previous approaches.

The intermodal assignment-simulation model (Abdelghany and Mahmassani 2001; Abdelghany 2001) represents special-purpose enhancements of the DYNASMART simulation-assignment tool developed to evaluate ITS applications in traffic networks (Jayakrishnan et al. 1994; Abdelghany et al. 1999; and Mahmassani et al. 2000). The model dynamically assigns travelers to the different modes and routes in the network according to prevailing traffic conditions, which result from applying a certain network control scheme. Two different traffic assignment scenarios are considered: single-mode assignment and intermodal assignment. In the single-mode assignment scenario, all travelers are assumed to use private cars. Transit vehicles are simulated only as background traffic for the auto traffic. This scenario examines the impact of priority primarily on network traffic conditions in situations where transit mode usage is very low, and only minimal shifts can be expected from the bus improvements. The intermodal assignment scenario considers possible change in the mode share because of change in transit vehicle travel time due to bus priority at selected signalized intersections in the network.

Three bus priority strategies are considered in the analysis: phase extension, red truncation, and phase advance.

This article begins with a description of the assignment-simulation methodology, followed by a description of the bus priority strategies considered in the study. Different sets of experiments are then presented to show the model capabilities and to illustrate the significance of evaluating bus priority in an intermodal dynamic network assignment framework. The results of these experiments together with analysis of the main findings are provided. Conclusions and possible extensions are given in the final section.

Dynamic Assignment-Simulation Methodology

The methodology is based on the DYNASMART assignment-simulation model, enhanced for intermodal transportation network applications. The logic of the core simulation-assignment procedures is described elsewhere (Jayakrishnan et al. 1994; Abdelghany et al. 1999; Mahmassani et al. 2000), and only aspects directly relevant to the present application will be highlighted. The model considers different travel modes such as passenger cars, buses, metro/subway and high-occupancy vehicles (HOV). It captures the interaction between mode choice and traffic assignment under different traffic control schemes, and under different information provision strategies. Figure 1 illustrates the framework and the different components of the methodology.

The model generates travelers based on predetermined time-dependent origin-destination (OD) zonal demands. Each generated traveler is assigned a set of attributes, which include his or her trip starting time, generation link, final destination, and a distinct identification number. An indicator is also assigned to each traveler to denote car ownership status. In parallel, transit vehicles are generated according to a predetermined schedule and follow predetermined routes. Prevailing travel times on each link are estimated using a vehicle simulation component that moves vehicles and captures the interaction between private cars and transit vehicles. The model also considers values of other attributes (e.g., parking costs, highway tolls, transit fares, out-of-vehicle time, and number of transfers along the route) that may be used by travelers to evaluate different mode-route options.

Using these attributes, a mode-route decision module is activated to provide travelers with a superior set of mode-route options. This route-mode decision module consists of a multiobjective shortest path algorithm, which generates a set of supe-

Figure 1. Overall Modeling Framework

rior paths in terms of the set (or a suitable subset) of the attributes listed above. Considering the diverse set of traveler behavioral rules as well as different levels of information availability, travelers evaluate the different mode-route options to select their preferred alternative. These behavior rules and response mechanisms are implemented through the user behavior component of the methodology. Each option represents an initial plan that a traveler follows (unless he or she receives en-route real-time information suggesting a better plan) to reach his or her final destination. This plan describes the used mode(s) and the route to be followed including any transfer node(s) along this route. Based on the available options, a traveler may choose pure mode or a combination of modes to reach his or her final destination.

If a traveler chooses private car for the whole trip or part of it, a car is generated and moved into the network with a starting time equal to its driver's starting time. Each newly generated vehicle is assigned a unique ID number. Vehicles are then moved in the network subject to the prevailing traffic conditions until they reach their final destinations or the next transfer node along the prespecified route (in the case of an intermodal trip). If a traveler chooses a transit mode, he or she is assigned to a transit line such that the passenger's destination is a node along the path followed by the bus. If no single line is found or if the passenger is not satisfied with the available single line, the passenger is assigned to a path composed of two lines with one transfer node, such that the passenger's destination is a node along

the path followed by the second bus. If no two such lines are found, the search is continued for three lines with two transfers. It is assumed that no passenger would be willing to incur more than two transfers in his or her trip. Thus, if no path with a maximum of two transfers is available, the trip is indicated as infeasible. Given the passenger's origin node, the nearest transit stop along the first line in the passenger's path is determined, and he or she waits until the arrival of the next vehicle that serves that transit line. When a transit vehicle arrives at a certain stop, all passengers who are waiting for a vehicle serving this specific transit line get on board. These passengers depart to reach their final destination or the next transfer node along their route.

Upon the arrival of a vehicle (private car or transit vehicle) to a certain destination node, this destination is compared to the final destinations and transfer of each traveler on board. If it matches the final destination of a traveler, the current time is recorded for this traveler as his or her arrival time. If it matches a transfer, the traveler transfers to the next transit line in his or her plan. The nearest stop is again determined and the traveler waits for his or her next transit vehicle. The time difference between arrival at the transfer node and boarding of the next line is calculated as the waiting time at the current transfer node for this traveler. This process is continued until all vehicles reach their final destinations carrying all travelers. If a traveler misses the initially assigned transit vehicle because of late arrival or because the vehicle does not have enough space, the model allows the traveler to replan the trip. Available options are regenerated for this traveler and he or she makes a selection through the behavior component.

The vehicle simulation component is time-based and moves individual vehicles along links according to local speeds determined consistently with macroscopic traffic stream models (i.e., a speed-density relation of modified Greenshield's form is used in this implementation). For every time step, the number of vehicles on each link is calculated using conservation principles; numbers in each class of vehicles in the traffic mix are kept separately. Consistently with the macroscopic logic for modeling vehicle interactions, average passenger car equivalent factors are used to convert each vehicle type to the equivalent passenger car units. Also, the effect of bus stopping at a bus stop on the link is considered by reducing the link capacity for a period equal to the bus dwell time. The resulting equivalent-car concentration is then calculated for each link, and used to estimate the corresponding speed through the speed-density relation. These speeds, updated continually to reflect prevailing conditions, determine vehicular movement on that link.

Queuing and turning maneuvers at junctions are explicitly modeled, thereby ensuring adherence to first-in, first-out principles as well as traffic control devices at junctions. Vehicles that reach the end of the link and are unable to move to a downstream link because of capacity limitations join the back of the vehicle queue at the upstream end of the link. The physical size of the queue is explicitly represented in the simulation, resulting in the division of the link into a moving part and a queuing part. Vehicles that reach the back of the queue must wait until vehicles ahead of them are discharged. All inflow and outflow constraints that limit the number of vehicles entering and leaving each link under the prevailing traffic control are implemented. The right-of-way among competing movements is allocated according to the existing control device at every intersection. The outflow constraints limit the maximum number of vehicles allowed to leave any given approach of an intersection, reflecting the available vehicles in queue and outflow capacities of the approach under the prevailing control. The inflow constraints bound the total number of vehicles that are allowed to enter a link. These constraints bound the total number of vehicles from all approaches that can be accepted by the receiving link, which reflects both physical storage consideration and inflow throughput capacity.

Signal Control and Bus Priority Strategies

The DYNASMART model and its intermodal extension provide the ability to explicitly model an array of control devices for street intersections such as yield signs, stop signs and signal control, which includes pretimed and actuated control. In this article, three bus priority strategies are evaluated. This section describes the simulation logic of the actuated signal logic and the bus priority algorithm. A description of the logic of the other control elements can be found in Hu (1995).

Figures 2, 3, and 4 illustrate the actuation logic for the three different bus priority strategies, namely phase extension, red truncation, and phase advance, respectively. These strategies are implemented by modifying the vehicle-actuated signal control logic of DYNASMART. In this logic, the green time for a given phase is determined based on the number of vehicles that would have reached the intersection at the end of the current simulation interval (in the absence of a queue). The green time is subsequently extended as appropriate at each simulation interval until “max out” is reached, or terminated if no longer needed, thereby emulating “gap out.”

Figure 2. Logic of Actuated Signal Control with Phase Extension Bus Priority

Figure 3. Logic of Actuated Signal Control with Red Truncation Bus Priority

In the phase extension case, if a bus is detected on any of the approaches served during the current phase, the green time required to move this bus through the signal is estimated. If the extension required for the bus is greater than the extension required to accommodate all vehicles that would have reached the stop line over the red interval, the green time for this phase is extended unless the maximum green value is reached. In other words, the green extension should be within the allowable maximum green time for that phase, and no exception is made for the bus. The logic of this priority strategy is detailed in Figure 2. Assume the start

Figure 4. Logic of Actuated Signal Control with Phase Advance Bus Priority

time of phase i is $t_{i,s}$. The current green time of phase i is $G_{i,T-1}$, which is assigned to phase i at the end of simulation interval $T-1$. For each simulation interval, the green time extension, if needed, is calculated as the longer of the time required to accommodate all vehicles that would reach the stop line at the end of the simulation time interval T and the time required to free any detected bus on any of the approaches that are served during phase i . If the remaining green time, $G_{i,T-1} - (t - t_{i,s})$, is less than this required extension, the calculated green extension is added to the green time of the phase i . If the allocated time exceeds the maximum green time, the maximum green time is given to this phase. Otherwise, the signal enters

the change interval and switches to another phase. Thus, the next phase j starts at time $t_{j,s} = G_{i,T} + t_{i,s} + \text{yellow}_i$ and has the green time $G_{j,T} = G_{\min}$.

In the red truncation and phase advance cases, if a bus is detected on any of the intersection approaches, one of the following two cases could be encountered. First, the phase that serves this bus is already active. In this case, the phase extension logic described above is followed and no change in the phase sequence is made. Second, the phase that serves the detected bus is not the active phase. In this case, the phase that serves the detected bus is somehow advanced to minimize bus delay at the intersection.

If the red truncation logic is implemented, only the minimum green value plus the yellow interval is given to the remaining phases in the cycle to advance the bus phase. For example, consider Figure 3, which represents the three-phase traffic signal in the sequence of i , j , and k , respectively. If a bus is detected in one of the approaches that is served by phase i , while phase j is active, both phases j and k are given the minimum green plus yellow. Then, phase i is initiated to clear the bus.

If the phase advance is implemented, the green of the active phase is immediately cut off (after providing the appropriate yellow interval) and the bus phase is activated directly. For example, in Figure 4, if a bus is detected in one of the approaches that is served by phase i , while phase j is active, the green is cut in phase j and a yellow is given. Also, phase k is completely skipped to start phase i to clear the bus.

Experimental Design

A set of simulation experiments are designed to illustrate the model capabilities. Figure 5 depicts the test network used in these experiments, which represents the south-central corridor in Fort Worth, Texas. The network consists of part of about 22 km of the freeway (I-35W) surrounded by a street network with a total of 178 nodes and 441 links. All signalized intersections (61 intersections) are assumed to have vehicle-actuated controls and capable of implementing the three bus priority strategies described earlier. The maximum green value was set as 25 seconds for the four-phase intersections and 55 seconds for the two-phase intersections. The network does not contain three-phase signalized intersections. The minimum green is set as 10 seconds for all cases. The unsignalized intersections are set as follows: no control (62 intersections), yield sign control (24 intersections), and stop sign control (31 intersections). No signal coordination scenarios are considered

Figure 5. Test Network Showing Simulated Transit Lines

in these experiments. However, we strongly believe that studying bus priority in coordinated signal system is a logical extension for the current research. Twelve hypothetical bus lines, presented as bold lines in Figure 5, are assumed to connect the main attractions in the network through the main corridors.

Travelers are assumed to have pretrip information on available alternatives. They are also assumed to evaluate these different alternatives according to a prespecified deterministic generalized cost function. Two main trip attributes are considered in these experiments: total travel time and total travel cost. Trip travel time is estimated based on the time-varying network conditions, while trip cost is assumed to be fixed. A travel cost of \$0.20 per link (which could also vary per link) is assumed across all private car users. A fixed value of time across all travelers taken as \$6.0 per hour, is used to calculate the generalized cost measure. Of course, a distribution of these values could readily be used instead. A flat bus fare of \$0.50 is assumed for the 12 bus lines considered. All travelers are assumed to own a car, and to consider transit and intermodal trips that involve at most one transfer along the trip. Thus, four modal options are assumed to be available for each individual: private car, one bus line, two bus lines with one connecting transfer, and park-and-ride with one intermodal transfer. In all experiments, the average vehicle travel and stop times, and the average bus travel and stop times are recorded.

Four experimental factors are considered in this study. One of these factors pertains to the bus priority strategy applied at the signalized intersections: (1) phase extension, (2) red truncation, and (3) phase advance. This factor reflects different levels of bus priority over the automobiles. As described earlier, in the phase extension strategy, the right-of-way is guaranteed only if the bus arrives during the phase that serves this particular approach. In the red truncation and phase advance strategies, the green is advanced to serve the detected bus earlier. The second factor considers two different traffic assignment scenarios: single-mode assignment and intermodal assignment. In the single-mode scenario, buses are simulated only as background traffic. All travelers are assumed to use private cars regardless of the improvements in bus service due bus priority. In the intermodal scenario, travelers are assumed to evaluate the bus option and select it only if it dominates the private car option (according to the mode choice behavior rule). The capability to consider such mode shifts in response to transit operational improvements is one of the contributions of the methodology presented in this article. The third and fourth experimental factors reflect different network congestion levels and different bus intensities in the network, respectively. Three demand

levels are considered, corresponding to about 13,500, 9,500 and 6,500 vehicles, respectively, over a 20-minute peak loading period. The first demand level represents high traffic congestion conditions, while the last demand level represents light congestion conditions, with the middle level reflecting mild congestion. For the fourth factor, two bus frequency levels are tested which are 12 and 24 buses per hour, respectively. The 12 bus lines shown in Figure 5 are assumed to operate with the same frequency in each experiment.

Results and Analysis

Table 1 presents a comparison of network performance across the three bus priority strategies, under the single-mode assignment scenario. Each bus priority strategy is evaluated through a separate run of the simulation-assignment model. Furthermore, each of these scenarios is compared against the do-nothing scenario, where no bus priority is considered. In these four experiments, a high bus frequency is considered at a rate of 24 per hour per line. Table 2 presents the same setting as Table 1, however, it considers lower bus frequency at a rate of 12 per hour per line. In the single-mode assignment scenario, buses are simulated only as background traffic and are not considered as a travel mode option. Therefore, the total number of simulated vehicles remains the same, and the effect of priority is primarily in terms of its traffic operational impacts. The average vehicle travel and stop times, together with the average bus travel and stop times are recorded for the three different demand levels. These performance measures are compared with the do-nothing no-bus-priority case (base case).

Regarding savings in the average bus travel and stop times, the two priority strategies (red truncation and phase advance) in which the green is advanced in favor of the detected buses outperform the phase extension strategy. For example, for the highest demand case in Table 1, percentage savings of about 17 percent and 52 percent in the average bus stop time are recorded for the red truncation and the phase advance strategies, respectively. These savings are in turn reflected in average bus travel time savings of 7 percent and 22 percent under the red truncation and the phase advance strategies, respectively. The phase advance strategy, which provides immediate green for any detected bus, outperforms the red truncation strategy in which any detected bus must wait for the other phases in the cycle to receive their minimum green. In all experiments, the effect of the phase extension strategy on the savings in the average bus travel and stop times appears to be minimal.

Table 1. Comparison of Different Bus Priority Strategies Considering Single-Mode Assignment Where Bus Frequency = 24 Bus/Hour

Table 2. Comparison of Different Bus Priority Strategies Considering Single-Mode Assignment Where Bus Frequency = 12 Bus/Hour

According to this set of simulation experiments, the corresponding deterioration in the average vehicle travel time, after introducing bus priority, is low. The maximum observed increase in the average vehicle travel time under the single-mode assignment scenario is less than one minute ($\approx 4\%$). In some instances, overall savings in the average vehicle travel time were obtained. For example, in Table 1, for the mild congestion level, a one-minute reduction ($\approx 5\%$) in average vehicle travel time is recorded for the phase advance strategy. The reason for this apparent “win-win” improvement lies in drivers adjusting their travel paths. Major changes in signal timing at the network level may induce travelers to change paths to take advantage of lower travel times per costs (Abdelfatah and Mahmassani 1998). For instance, the gained day-to-day travel experience, and/or receiving information on traffic congestion, could allow travelers to modify their paths to take advantage of the savings in travel times per costs. This behavioral phenomenon is explicitly modeled in this set of experiments. Travelers are assumed to select the best path for their trips after the change to signal timing with bus priority. A traveler could therefore completely avoid passing through an intersection with bus priority if considerable delay is to be encountered. Incorporating the effect of traveler redistribution in the network in response to major operational changes is an essential capability of the present methodology for the network-level evaluation of traffic operational measures.

Tables 3 and 4 provide a basis for comparing the effect of bus priority on network performance under the intermodal assignment scenario. The phase advance strategy, which is shown to provide the most savings in the bus travel times, is used in this set of experiments. Table 3 shows the results for the high bus frequency rate (24/hour/line), while Table 4 shows the results for the low frequency rate (12/hour/line). In this scenario, bus transit is considered an option in the mode choice set of each traveler. Travelers can therefore switch to transit if this option becomes preferable to private car in light of improvements brought about by the priority strategies. As such, the results of this set of experiments could be interpreted as long-term benefits associated with providing bus priority at signalized intersection. For example, in the highest congestion case in Table 3, a savings of about 24 percent is observed in the average bus travel time after introducing the phase advance bus priority strategy. This savings in average bus travel time results in about 0.4 percent decrease of private car share, 2.9 percent increase in bus share, and more than one minute (4.5%) savings in average vehicle travel time. Similarly, in the highest demand level in Table 4, a savings of 21 percent in average bus travel time reduces private car share by 1.45 percent and increases transit share by about

Table 3. Comparison of Different Bus Priority Strategies Considering Intermodal Assignment Where Bus Frequency = 24 Bus/Hour

Table 4. Comparison of Different Bus Priority Strategies Considering Intermodal Assignment Where Bus Frequency = 12 Bus/Hour

6.57 percent (including park-and-ride), resulting in 3 percent savings in average vehicle travel time.

These results highlight the importance of considering potential modal shifts and reassignment in evaluating traffic network performance under different control schemes, especially when these schemes are expected to affect the modal split in the network (such as bus priority). The results obtained here are intended for illustration purposes only to highlight the methodological approach and its capabilities. The percentage decrease in auto traffic and associated savings in travel time depend mainly on the value of the parameters used in the mode choice function and other input parameters used in the application.

Conclusions

In this research, three different bus priority strategies are evaluated using a dynamic traffic assignment-simulation framework. These strategies include phase extension, red truncation, and phase advance. A specially modified version of the multimodal assignment-simulation model, DYNASMART, is used in this study. The model dynamically assigns travelers to the different modes and routes according to the prevailing traffic conditions. A set of simulation experiments is performed to compare these bus priority strategies considering two different assignment scenarios: single-mode assignment and intermodal assignment. The results of these experiments show that the phase advance and red truncation strategies outperform the phase extension strategy. In contrast to previous studies, when correctly modeling the vehicles reassignment phenomenon, the deterioration in the average vehicle travel time was minor. Under the intermodal assignment scenario, the savings in average bus travel time could potentially attract more travelers to use the bus instead of private cars. This reduces the congestion level in the network as indicated by the reduction in average vehicle travel time. Extension of this work includes testing the model in real-world situations considering different operational scenarios. Another extension is to study bus priority strategies in a coordinated signal system to evaluate its possible disruption effect on the timing of the coordinated signals.

References

- Abdelfatah, A. S., and H. S. Mahmassani. 1998. System optimal time-dependent path assignment and signal timing in traffic network. *Transportation Research Record* 1645: 185–193.
- Abdelghany, K. 2001. Stochastic dynamic traffic assignment for intermodal transportation networks with consistent information supply strategies. Ph.D. Dissertation. The University of Texas at Austin, Austin, TX.
- Abdelghany, K., D. Valdes, A. Abdelfatah, and H. Mahmassani. 1999. Real-time dynamic assignment and path-based signal coordination: Application to network traffic management. *Transportation Research Record* 1667: 67–76.
- Abdelghany, K., and H. S. Mahmassani. 2001. Assignment-simulation model for intermodal transportation networks. *Transportation Research Record* 1771: 52–60.
- Baker, R., et al. 2002. *An overview of transit signal priority handbook*. Washington, DC: Intelligent Transportation Society of America.
- Bell, M. G. H. 1992. Future directions in traffic signal control. *Transportation Research A*, 26: 303–313.
- Chang, E., and A. Ziliaskopoulos. 2003. Data challenges in development of a regional assignment: Simulation model to evaluate transit signal priority in Chicago. *Transportation Research Record* 1841: 12–22.
- Chang, G-L., M. Vasudevan, and C. Su. 1995. Bus-priority under adaptive signal control environments. *Transportation Research Record* 1494: 146–154.
- Chang, J., J. Collura, F. Dion, and H. Rakha. 2003. Evaluation of service reliability impacts of traffic signal priority strategies for bus transit. *Final Report*. National ITS Implementation Research Center. Virginia Tech Transportation Institute.
- Chard, B. M., and C. J. Lines. 1987. TRANSYT: The latest developments. *Traffic Engineering and Control* 28: 387–390.
- Garrow, M., and R. Machemehl. 1997. *Development and evaluation of transit signal priority strategies*. Report SWUTC/97/472840-00068-1. Austin, TX: Center for Transportation Research.

- Hu, Ta-Yin. 1995. Dynamic analysis of network flows under advanced information and control systems. Ph.D. Dissertation. The University of Texas at Austin, Austin, TX.
- Heydecker, B. 1983. Capacity at a signal-controlled junction where there is priority for buses. *Transportation Research B*, 17: 341–357.
- Jayakrishnan, R., H. S. Mahmassani, and T.-Y. Hu. 1994. An evaluation tool for advanced traffic information and management systems in urban network. *Transportation Research C*, 2: 129–147.
- Khasnabis, S., R. R. Karnati, and R. K. Rudra Raju. 1996. A NETSIM based approach to evaluate bus priority strategies. *Transportation Research Record* 1554: 80–89.
- Longfoot, J. E. 1982. SCATS—Development of management and operation systems. International Conference on Road Traffic Signalling, London, United Kingdom.
- Lowrie, P. R. 1982. The Sydney coordinated adaptive traffic system—Principles, methodology, algorithms. N.S.W., Australia: Department of Main Roads.
- Mahmassani, H. S., et al. 2000. DYNASMART-P: *Intelligent transportation network planning tool*. Austin, TX: Center for Transportation Research, The University of Texas at Austin.
- Mirchandani, P., and D. Lucas. 2004. Integrated transit priority and rail/emergency priority in real-time traffic adaptive signal control. *Intelligent Transportation Systems Journal* 8: 101–115.
- Nash, A. 2003. Implementing Zurich's transit priority program. *Transportation Research Record* 1835: 59–65.
- Radwan, A. E., and D. A. Benevell. 1983. Bus priority strategy: Justification and environmental aspects. *Journal of Transportation Engineering* 109: 88–106.
- Sims, A. G., and A. B. Finlay. 1984. SCATS, splits and offsets simplified (S.O.S.). *ARRB Proceedings* 12, Part 4.
- Smith, H., B. Hemily, and M. Ivanovic. 2005. *Transit signal priority (TSP): A planning and implementation handbook*. Washington, DC: Intelligent Transportation Society of America.

- Sunkari, S. R., T. U. Beasley, and D. B. Fambro. 1995. Model to evaluate the impacts of bus priority on signalized intersections. *Transportation Research Record* 1494: 117–123.
- Yagar, S. 1993. Efficient transit priority at intersections. *Transportation Research Record* 1390: 10–15.

About the Authors

KHALED ABDELGHANY (khaled@engr.smu.edu) received a Ph.D. in civil engineering from the University of Texas Austin in 2001, and B.Sc. and M.Sc. from Cairo University in 1992 and 1996, respectively. He is currently an environmental and civil engineering assistant professor at Southern Methodist University, Dallas. Prior to joining SMU, Dr. Abdelghany worked in the operations planning group in the Information Services Division at United Airlines. His research interests include modeling intermodal transportation networks, intelligent transportation systems, and airlines operation management. Dr. Abdelghany has published in several journals, including *Transportation Research Record*, *Annals of Operations Research*, and *Journal of Air Transport Management*. He is a member of American Society of Civil Engineers, Institute of Transportation Engineers, and Institute for Operations Research and the Management Sciences.

AHMED ABDELGHANY (Abdel776@erau.edu) is an assistant professor at the College of Business, Embry-Riddle Aeronautical University. Prior to his association with Embry-Riddle, Dr. Abdelghany was an assistant professor in the Department of Civil and Environmental Engineering at the University of Alaska, Fairbanks. Also, he worked for several years as a senior analyst in the Information Services Division of United Airlines. Dr. Abdelghany holds a doctorate in civil engineering from the University of Texas at Austin (2001). His research in the areas of transportation planning, traffic engineering, and airline operation management have appeared in several journals, including *Transportation Research Record*, *Annals of Operations Research*, *Air Transportation Management*, and *Air Traffic Control Quarterly*.

HANI S. MAHMASSANI (masmah@mail.umd.edu) received a Ph.D. in transportation systems from the Massachusetts Institute of Technology in 1982, an M.S. in transportation engineering from Purdue University in 1978, and a B.S. in civil engineering from the University of Houston in 1976. He is the first holder of the Charles Irish Sr. Chair in Civil and Environmental Engineering at the University of Maryland, where he is also the founding director of the Maryland Transportation

Initiative. He joined the University of Maryland in August 2002, after 20 years on the faculty at the University of Texas at Austin, where he was most recently the A. Abou-Ayyash Centennial Professor in transportation engineering, professor of management science and information systems, and director of the Advanced Institute for Transportation Infrastructure Engineering and Management. He specializes in multimodal transportation systems analysis, planning and operations, dynamic network modeling and optimization, transit network planning and design, dynamics of user behavior and telematics, telecommunication-transportation interactions, large-scale human infrastructure systems, and real-time operation of logistics and distribution systems.

AKMAL ABDELFATAH (akmal@aus.ac.ae) is an assistant professor of civil engineering at the American University of Sharjah, United Arab Emirates. He has a Ph.D. from the University of Texas at Austin and has worked as a transportation planning and traffic engineering consultant/researcher on many projects in the Middle East and the United States. Dr. Abdelfatah's research interests are focused on dynamic traffic assignment, traffic operations, and ITS applications.

Slugging in Houston—Casual Carpool Passenger Characteristics

Mark W. Burris, Texas A&M University
Justin R. Winn, Wilbur Smith Associates

Abstract

In the last 30 years, determined travelers have developed a new method of travel that offers the benefits of traveling on an HOV lane without forming traditional carpools. Casual carpools, also known as “slugging,” are impromptu carpools formed among strangers to meet the occupancy requirements of HOV lanes. In this research, survey respondent data from Houston, Texas, were used to examine casual carpool passengers.

Results of the analyses revealed that being on a commute trip, making more trips per week, being between the ages of 25 and 34, and having professional/managerial or administrative/clerical occupations all increased the likelihood of a traveler choosing to casual carpool. Additionally, having a household income between \$25,000 and \$35,000 significantly reduced the likelihood of casual carpooling.

Understanding the types of travelers who casual carpooled and the information gleaned in these analyses can be used to better evaluate HOV and HOT lane use and performance. Casual carpool passengers can comprise a significant portion of HOV/HOT lane person movement and should be considered when investigating HOV or HOT lane implementation.

Introduction

As congestion has worsened in our nation’s metropolitan areas, transportation professionals have explored various methods to increase the effective use of the

transportation infrastructure. One such method is the implementation of high-occupancy vehicle (HOV) lanes. HOV lanes are typically built on congested free-ways, and allow vehicles that meet specified occupancy requirements to bypass delays associated with driving alone on congested general-purpose lanes (GPLs) of the freeway. HOV lanes encourage carpooling and increase person movement along congested corridors (Turnbull 2004). HOV lanes promote the increase of person movement through higher vehicle occupancies by providing travel time savings to carpoolers (Turnbull 2004).

In the last 30 years, determined travelers have developed a new method of travel that allows them to receive the benefits of traveling on the HOV lane without forming traditional carpools (LeBlanc 1999). This new mode, known as casual carpooling or "slugging," consists of impromptu carpools formed among strangers to meet the occupancy requirements of HOV lanes.

The process of forming a casual carpool is relatively simple. Casual carpool passengers typically meet in a public area that has ample available parking, nearby public transit as an alternate mode in case a casual carpool is unavailable, and close proximity to the HOV facility. Drivers (also known as "body snatchers") arrive and pick up enough passengers to meet the HOV lane eligibility requirements. Drivers then travel along the HOV lane and drop off passengers in a public location, typically in the downtown area of a city. Details of the casual carpool process vary slightly depending on location.

Currently, organized casual carpooling occurs in three U.S. metropolitan areas: Washington, D.C. (LeBlanc 1999; Reno, Gellert, and Verzosa 1989; Spielberg and Shapiro 2000), San Francisco (Beroldo 1990; RIDES for Bay Area Commuters, Inc. 1999), and Houston (Ojah and Burris 2004).

The slugging system in Washington, D.C., which has existed for more than 30 years, is well organized with a large number of pick-up and drop-off locations and a website (<http://www.slug-lines.com>) for local slugs and bodysnatchers. Conversely, slugging in the San Francisco Bay area occurs in one general area. Passengers and drivers meet in the morning peak period to form carpools and cross the Bay Bridge. Passengers are usually dropped off in the downtown area and typically use transit for their return trips. Casual carpooling in Houston occurs at three locations, all of which feed the downtown area. Passengers meet at park-and-ride locations on I-10 and US 290 that have direct access to HOV lanes. Drivers arrive throughout the morning and pick up the necessary number of passengers to meet the HOV occupancy requirement.

An important similarity among these three locations is that the HOV lanes require three or more occupants, whereas the vast majority of HOV lanes in the United States allow vehicles with two or more occupants. This higher occupancy requirement plays a significant role in the formation of casual carpools. At the same time, urban freeways are becoming increasingly congested, encouraging more travelers to use HOV lanes and, therefore, more HOV lanes will have to increase their restrictions to three or more occupants. As more HOV lanes institute higher occupancy restrictions, the need to understand the complex issue of casual carpooling becomes exceedingly important.

Despite its presence for more than three decades, casual carpooling has yet to expand beyond these three cities. Casual carpooling can increase person movement along congested corridors and can provide substantial travel time savings for users. However, it is not marketed or regulated in any way by transportation officials. As these carpools are formed among strangers, there are potential liability issues that could surround agency support of casual carpooling. This does not mean that the effects of casual carpooling and characteristics of its users are not important to transportation engineers and planners. With the potential to increase person movement and provide better HOV lane utilization, casual carpooling could represent a significant portion of daily HOV lane travelers, particularly if (1) more HOV lanes restrict usage to vehicles with three or more occupants and/or (2) future HOV facilities are constructed with casual carpoolers in mind.

This research took an in-depth look at casual carpooling in Houston, with emphasis on the travel time savings gained by those choosing this mode. Additionally, survey data were examined to gain insight into the socioeconomic and commute characteristics of Houston casual carpoolers and to generate mathematical models that further consider the socioeconomic and commute characteristics that indicate a higher likelihood of a traveler choosing to casual carpool.

Casual Carpooling in Houston, Texas

The casual carpooling phenomenon appears to have begun more recently in Houston than in Washington or San Francisco. Although no documented evidence exists to pinpoint when casual carpooling began in Houston, newspaper interviews of casual carpool users indicate that the mode has been used since 1990 (Wall 2002).

Casual carpooling in Houston occurs in three locations: Kingsland Park-and-Ride lot, Addicks Park-and-Ride lot, and Northwest Station Park-and-Ride lot. The

Kingsland and Addicks lots are located on I-10 (Katy Freeway) west of downtown Houston; the Northwest Station lot is located on US 290 (Northwest Freeway) northwest of downtown Houston. Each park-and-ride facility is used primarily for transit and offers direct-connect ramps to a barrier-separated HOV lane. Casual carpool passengers form a line near transit pick-up locations and wait for drivers. Drivers arrive periodically and pick up enough passengers to meet the HOV lane occupancy requirement. If passengers are unable to join a casual carpool, they have the option of using transit, which runs throughout the day from the park-and-ride facilities. Most casual carpools form between 6 A.M. and 9 A.M. (Ojah and Burris 2004). As bus headways increase significantly after 9 A.M. and most commuters have already traveled to work, the use of casual carpools decreases significantly, dropping to near zero.

Casual carpooling in Houston occurs exclusively on the city's two high occupancy/toll (HOT) lanes (the only two HOV lanes that restrict usage to three or more occupants during part of the day). The vehicle occupancy requirement on I-10 and US 290 is HOV2+ for most of the day, but, due to congestion, it was raised to HOV3+ from 6:45 A.M. to 8 A.M. and 5 P.M. to 6 P.M. on I-10 and from 6:45 A.M. to 8:00 A.M. on US 290. The lanes are closed temporarily during the middle of the day for direction reversal. During the HOV3+ periods, HOV2 vehicles may enter the lane by paying a \$2 toll. This program was first implemented on the Katy Freeway HOV lane in 1998 and was expanded to include the Northwest Freeway HOV lane in 2000. Participants were required to open an account, mount a transponder and hangtag on their vehicle, and pay a \$2.50 monthly service charge. The behavior of casual carpoolers would change during the restricted periods as drivers would typically pick up only one passenger during the HOV2+ periods, but would pick up two passengers during the HOV3+ period. The majority of casual carpooling occurs during the HOV3+ period (see Table 1 on p.29). A separate survey of drivers who paid the \$2 toll to travel in the lane during peak periods revealed very few (7%) pick up a single slug (Burris and Appiah 2004). This was not surprising as the cost (extra time) spent picking up the second slug was relatively small compared to the \$2 toll.

Data

The analysis of casual carpool passenger behavior required socioeconomic and commute characteristics of casual carpool passengers. Most of the necessary data were collected by the Texas Transportation Institute through a survey distributed to casual carpool passengers as part of a larger traveler survey in November 2003 (Burris and Stockton 2004). However, additional data on corridor travel speeds and carpool headways were collected to estimate the time savings benefit gained by casual carpoolers.

Based on video license plate data, surveys were mailed to drivers using the general purpose and HOV lanes during both peak and off-peak traffic periods. Each survey was designed specifically for the group to which it would be distributed (HOV lane during peak periods, main lane off-peak, etc.). Additionally, surveys were produced for transit users and casual carpool passengers. However, rather than being mailed, the transit passenger surveys were conducted on-board the buses, and casual carpoolers were handed surveys while they waited for a ride. All surveys had questions regarding trip purpose, time of day, and socioeconomic characteristics. A set of questions specific to casual carpooling was also included. A series of stated preference questions that asked respondents to identify their preferred travel mode given specific travel time and fee (toll) options was included in all surveys.

A total of 539 questionnaires were distributed to casual carpool passengers at the three park-and-ride facilities in Houston. Of the 539 surveys, 216 were returned for a total response rate of approximately 40 percent. On the day the surveys were handed out, 7 percent of casual carpool passengers refused to take one, indicating an approximate total of 578 casual carpool passengers that day. This number closely matched casual carpool passenger counts performed in June 2003. Therefore, even though relatively little was known about the total number of casual carpoolers in Houston, the 216 returned surveys were believed to be sufficient so that the responses were representative of the group.

The final dataset used in the analysis excluded a number of the 216 responses. For this analysis, only trips beginning between 6 A.M. and 9 A.M. (eliminating 8 respondents) were included to focus on the time period during which the vast majority of casual carpooling occurred and when the primary alternative mode (transit) had consistent headways. Additionally, for the calculation of descriptive statistics and estimation of mode choice model coefficients, only respondents who used casual carpooling at least three to four times per week were considered to allow the analysis to focus on travelers who frequently casual carpoled. This

further reduced the dataset by another 59 respondents, leaving 149 respondents for the casual carpool analysis.

Travel Time Savings

The casual carpool passenger survey included questions regarding travel time savings, which provided travelers' perceived travel time savings on the HOV lane. To estimate the actual travel time savings gained by casual carpool passengers, travel time data along the HOV lanes as well as the GPLs were required. TranStar, Houston's traffic management center, recorded average speed data on the corridor. This information was used to calculate the various travel times (Houston TranStar Real Time Traffic Information). The data used in this analysis were average speeds along the HOV and GPLs for the entire 2003 year (not including weekends and holidays).

To calculate travel time savings offered by casual carpooling, consideration was made for the amount of time necessary to park at a carpool formation site and wait to join a carpool. Parking and wait times at the formation site were manually observed during a typical morning peak period. On Wednesday, June 30, 2004, three data collectors observed parking and wait times at the Addicks Park-and-Ride location on the Katy Freeway. One data collector observed people arriving at the facility and measured the amount of time necessary to walk from their cars to the casual carpool formation site. Forty-two persons were observed taking an average of 105 seconds (± 7.6 seconds at a 95 percent confidence interval) to walk from their cars to the site. Two other data collectors recorded the amount of time that casual carpool passengers waited in the casual carpool line prior to entering a vehicle. The 147 casual carpool passengers experienced an average wait time of 144 seconds (± 17.8 seconds at a 95 percent confidence interval). Combining the walking and waiting times with the travel time savings indicated that casual carpool passengers could save as much as 13 minutes over driving alone on the GPLs (see Table 1). Additionally, the number of casual carpool passengers was generally higher during times of larger travel time savings.

In comparing carpooling and riding transit, it was necessary to determine the approximate time spent waiting for a bus, as this wait time was the only travel time difference between the two modes. Transit users and casual carpoolers spent the same amount of time arriving at the park-and-ride lot and walking to the queues. Casual carpool passengers and transit users incurred similar travel times after being dropped off because carpool passengers were typically dropped off at

Table 1. Time Savings (in minutes) Gained by Casual Carpool Passengers Compared to Driving Alone on the GPLs

Note: The travel time savings calculation assumed very conservative values for the amount of travel time saved by casual carpoolers. For example, it was assumed access to the park-and-ride lot took several extra minutes over just entering the freeway as an SOV. Most likely, casual carpoolers who traveled when the estimated travel time savings was negative actually had positive travel time savings, but they did not meet the conservative assumptions used. For example, their access to the park-and-ride lot may have taken no extra time versus accessing the freeway as an SOV.

or near bus stops. Additionally, the in-vehicle time for the two groups was similar as these express buses only had 2 to 3 stops on their route (this includes the stop where slugging occurs and the destination stop). Bus headways for each of the three park-and-ride locations during the morning peak period were used to calculate average wait times. The average headway was 10 minutes on the Katy Freeway

and 8 minutes on the Northwest Freeway. The average time spent waiting for a bus was assumed to be half of the average headway based on the assumption of random arrivals of transit passengers (Meyer and Miller 2001). Casual carpoolers saved an average of 2 minutes 36 seconds over transit on the Katy Freeway and 1 minute 36 seconds on the Northwest Freeway.

Other factors besides travel time savings might have influenced the mode choice of the travelers. Monetary costs (e.g., transit fare, fuel) or trip purpose could have affected a traveler's decision (Wall 2002). Socioeconomic characteristics could also have had a major influence on a traveler's decision to casual carpool. Travelers may have valued the reliability of travel times on the HOV lane. The survey data were used to determine what, if any, trip and socioeconomic characteristics increased the likelihood of a traveler choosing to casual carpool on a frequent (3 or more times per week) basis.

Comparison of Traveler Characteristics by Mode

The survey data were initially examined for significant differences ($p \leq 0.05$) among four groups of travelers based on their primary mode choice: driving on main lanes, using HOV lane with a traditional carpool, casual carpooling, and transit. A Chi-Square test assessed significant differences among the binary variables, and a one-way analysis of variance (ANOVA) examined the continuous variables. Additionally, a Kruskal-Wallis test determined any significant difference between groups for the ordinal variables of age, income, and education.

The results of the statistical tests revealed significant differences among travelers in the four primary morning modes of travel (Table 2). The percentage of respondents on commute, recreation, school, and other trip types was significantly different among the four groups. Casual carpoolers were more likely to be on commute trips. The percentage of respondents ages 25 to 34 and 65+ was significantly different among modes. A much higher percentage of casual carpoolers were between ages 25 and 34. The average household size, percentage of single adult households and married without children households, and the number of vehicles per household also differed among modes, with HOV users having significantly larger households. A difference was also found for those with occupations that were professional/managerial, sales, homemaker, self-employed, or retired. Income ranges of \$25,000 to \$35,000, \$50,000 to \$75,000, \$100,000 to \$200,000, and \$200,000 or more were also different among the four mode choices.

Table 2. Descriptive Statistics of Surveyed Travelers

¹Significant ($p \leq 0.05$) difference when comparing all four modes.
²Significant ($p \leq 0.05$) difference when comparing casual carpooling and transit.

Next, similar statistical tests were performed to determine significant differences ($p \leq 0.05$) between travelers using just two mode choices: casual carpooling and transit. These mode choices were specifically examined due to their symbiotic relationship and the similarity of the modes since travelers on both modes (1) use park-and-ride lots, (2) have someone else drive, (3) travel on HOV lanes, and (4) are dropped off relatively close to their work. Also, casual carpoolers are often former transit users (Beroldo 1990), and in this study more than 90 percent still used transit for some of their similar trips (Table 3).

The results of the statistical tests (Table 2) revealed several significant differences between casual carpoolers and transit riders. A higher percentage of casual carpool passengers were on commute trips and between the ages of 25 and 34, while a higher percentage of transit riders were between the ages of 55 and 64. A significantly higher percentage of casual carpoolers had professional/managerial occupations, while a significantly higher percentage of transit riders had household incomes between \$25,000 and \$34,999.

Casual Carpool Passenger Characteristics

The surveys distributed to casual carpool passengers contained a series of questions that were exclusive to that group. These questions addressed the nature of each traveler's casual carpooling trip and his or her previous experience using the mode (Table 3). For this analysis only, both frequent and infrequent casual carpoolers were examined. The results provided insight into the practice of casual carpooling in Houston, including what modes were commonly used for return trips and how frequently respondents joined a casual carpool.

Survey responses indicated that most casual carpool passengers (65.3%) had never met their travel companions before. However, almost one third indicated that they had traveled with them once or twice, indicating that a relatively small community of people used the mode consistently. More than 75 percent of users noted that they casual carpoled at least three times per week. Passengers also cited saving money (62.8%) and slow bus service (52.6%) as the two primary reasons for casual carpooling. They indicated that they often use the bus for similar trips and for the evening return trip. They also noted that money is rarely given to the driver as compensation, which is consistent with casual carpooling practices elsewhere in the United States.

Table 3. Casual Carpool Passenger Characteristics (n = 208)

Note: Some percentages sum to over 100 percent as respondents could choose multiple answers for some questions

Mode Choice Model Estimation

To better understand casual carpoolers and the factors that affect their mode choice, discrete choice model coefficients were estimated for two sets of choices. The choice between casual carpooling and transit was evaluated with the first model. The second model examined traveler choice of four modes: casual carpool, transit, traditional carpool, and driving on GPLs.

Methodology

Both models were estimated as discrete choice models. Discrete choice models assume that each traveler makes his or her decision based on the utility of each mode (Ben-Akiva and Lerman 1985). The traveler's ultimate decision will be determined by both the systematic utility based on measured variables and the random utility of each mode. The model in this analysis was estimated using a logit model, which assumes that random utilities follow an extreme value distribution (Small and Winston 1999).

Casual Carpool versus Transit Mode Choice Model

Although many variables were tested when estimating the model coefficients, only those variables significant at the 95 percent confidence level and not correlated to other variables were left in the final model. The results of the discrete choice model are shown in Table 4. For this model, the null choice was casual carpooling. The utility function derived in the model describes the utility of the transit mode relative to the casual carpooling mode that had all coefficients equal to zero.

The results of the model highlight some of the factors that describe selected types of travelers who choose to casual carpool rather than use transit. The constant coefficient is positive, indicating that all else being equal, travelers were more likely to choose transit than casual carpooling. This was not surprising as many more travelers used transit than casual carpools. The results also indicated that having an income between \$25,000 and \$35,000 increased the traveler's likelihood to use transit rather than casual carpooling. However, being on a commute trip, making a higher number of total trips per week, and/or being between the ages of 25 and 34 increased the traveler's likelihood of forming casual carpools.

**Table 4. Model Coefficient Estimation Results
(Casual Carpooling vs. Transit)¹**

¹Base alternative is casual carpooling with utility of zero.
*Significant at the 95 percent confidence level.

Four-Option Mode Choice Model

Several sets of variables were used for testing the four-choice model, using the main lanes option as the null choice. Only variables significant at the 95 percent confidence level remained in the final model. The variables used in the model as well as which mode choice utility functions they were associated with are listed in Table 5, while the model estimation results are shown in Table 6.

The constants for the HOV, casual carpool, and transit modes were all negative, indicating that all else being equal, travelers were most likely to drive on the main lanes. The trip purpose, age, and occupation (professional) variables applied only to the casual carpooling utility function and indicated a number of factors influenced casual carpoolers' decisions. The coefficient for the trip purpose was positive, indicating that being on a commute trip increased the likelihood that a traveler

Table 5. Definitions of Variables Used in Logit Model (All Four Modes)

would choose casual carpooling over the other three modes, which duplicates the results of the previous model. Professional/managerial or administrative/clerical occupations also increased a traveler's likelihood to use casual carpooling over the other three modes. Thus, travelers with weekday jobs with typical workday hours were more likely to casual carpool. This was not surprising considering the times during which casual carpooling occurs. Travelers with typical workdays would be more likely to encounter peak-period congestion if they drove alone on the GPLs. The results also indicated being between the ages of 55 and 64 reduced a traveler's likelihood of casual carpooling, which reflected a possible increased willingness among younger persons to try a newer, less-utilized mode of transportation.

In addition, having an income between \$25,000 and \$35,000 reduced a traveler's likelihood of casual carpooling, which was surprising considering the relatively low expense of that mode. One possible explanation was that low-income persons already used transit for many of their other trips, and they chose to use transit

Table 6. Model Coefficient Estimation Results (All Four Modes)

¹Base alternative is driving alone on main lanes with utility of zero.
*Significant at the 95 percent confidence level.

during the times of casual carpooling as well. Another possible explanation was subsidized transit passes were available to low-income travelers. Travelers with subsidized transit passes would have little to no money-savings incentive to casual carpool. Also, the descriptive statistics indicated that travelers with incomes between \$25,000 and \$35,000 were less likely to make commute trips, leading to less use of casual carpooling because commuting is a primary factor that influences casual carpool use.

Summary

This research effort examined the use of casual carpooling in Houston, Texas. Survey results revealed that most casual carpool passengers often used transit for evening return trips and similar morning trips. Approximately 63 percent used casual carpooling to save money and about 53 percent used casual carpooling because of slow bus service. Most casual carpoolers (76%) used this mode three or more times per week. Casual carpool passengers were significantly more likely to be on commute trips and be between the ages of 25 and 34 (younger), but were significantly less likely to have household incomes between \$25,000 and \$35,000.

The results obtained in these analyses provided some information on the characteristics of travelers who chose to casual carpool. This information can be used to better evaluate HOV/HOT lane use and future lane development considerations. Casual carpooling has grown in popularity and should be considered when assessing potential corridor improvements. Although potential liability concerns would likely prevent agencies from actively promoting casual carpooling, they could encourage it passively by constructing park-and-ride HOV facilities that are conducive to the mode. Casual carpooling has the potential to improve the operation efficiency of HOV/HOT facilities by improving person movement. Although there are potential liability concerns, it may eventually become beneficial to promote casual carpooling as a viable mode alternative.

Acknowledgments

This article reflects the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. This article was a result of research conducted in cooperation with the Federal Highway Administration (FHWA), the Texas Department of Transportation (TxDOT), and the Metropolitan Transit Authority of Harris County, Texas. The authors gratefully acknowledge the con-

tributions of numerous individuals and organizations that made the successful completion of this article possible.

References

- Ben-Akiva, M., and S. Lerman. 1985. *Discrete choice analysis: Theory and application to travel demand*. Cambridge, MA: MIT Press.
- Beroldo, S. 1990. Casual carpooling in the San Francisco Bay Area. *Transportation Quarterly* 44 (1): 133–150.
- Burris, M., and J. Appiah. 2004. An examination of Houston's QuickRide participants by frequency of QuickRide usage. *Transportation Research Record* 1864, 22–30.
- Burris, M., and W. Stockton. 2004. HOT lanes in Houston—Six years of experience. *Journal of Public Transportation* 7 (3): 1–21.
- Houston TranStar Real Time Traffic Information. <http://traffic.tamu.edu>. Accessed June 15, 2004.
- LeBlanc, D. E. 1999. *Slugging: The commuting alternative for Washington, D.C.* East Point, GA: Forel Publishing.
- Meyer, D., and E. Miller. 2001. *Urban transportation planning*. New York: McGraw-Hill.
- Ojah, M., and M. Burris. 2004. *Quantification of casual carpooling in Houston*. Texas Transportation Institute.
- Reno, A.T., W. A. Gellert, and A. Verzosa. 1989. Evaluation of Springfield instant carpooling. *Transportation Research Record* 1212, 53–62.
- RIDES for Bay Area Commuters, Inc. 1999. *Casual carpooling 1998 update*. <<http://rideshare.511.org/research/pdfs/casualcarpool.99.pdf>> Accessed December 8, 2003.
- Small, K. A., and C. Winston. 1999. The demand for transportation: Models and applications. *Essays in Transportation Economics and Policy*. Washington, DC: Brookings Institute Press.
- Spielberg, F., and P. Shapiro. 2000. Mating habits of slugs: Dynamic carpool formation in the I-95/I-395 corridor of Northern Virginia. *Transportation Research Record* 1711, 31–38.

Turnbull, K. F. 2004. History of HOVs. Committee on High Occupancy Vehicles Systems, Transportation Research Board. <http://www.hovworld.com>. Accessed October 18, 2004.

Wall, L. 2002. In search of slugs: Impatient Houston-area commuters form impromptu carpools. *Houston Chronicle* (December 2).

About the Authors

MARK W. BURRIS (mburris@tamu.edu) specializes in congestion (or value) pricing and has been involved in many projects in this area. He has served in an evaluation and monitoring role for the Houston Value Pricing Project, Lee County Variable Pricing Pilot Project, Queue Jump Value Pricing Project, Fort Myers Beach Cordon Toll Study, and Traveler Credit Based Pricing. Prior to joining Texas A&M University in August 2001, he was a senior research associate at the Center for Urban Transportation Research (CUTR) at the University of South Florida in Tampa. He is a member of the American Society of Civil Engineers, the Institute of Transportation Engineers, and the Transportation Research Board's Economics Committee and Congestion Pricing Committee.

JUSTIN R. WINN (jwinn@wilbursmith.com) has worked as a transportation analyst in the Transportation Finance and Technology division of Wilbur Smith Associates in Dallas, Texas, since January 2005. He was previously a graduate research assistant with the Texas Transportation Institute at Texas A&M University in College Station where he earned a B.S. and M.S in civil engineering. Mr. Winn is a member of the Institute of Transportation Engineers and the International Bridge, Tunnel and Turnpike Association.

Office Development, Rail Transit, and Commuting Choices

Robert Cervero, University of California, Berkeley

Abstract

Decentralized employment growth has cut into transit ridership across the United States. In California, about 20 percent of those working in office buildings near rail stations regularly commute by transit, nearly three times transit's modal share among those working away from rail stations. Mode choice models reveal that office workers are most likely to rail-commute if frequent feeder bus services are available, their employers help cover the cost of taking transit, and parking is in short supply. Factors like trip-chaining and the absence of restaurants and retail shops near suburban offices, however, deter transit-commuting. Policy-makers can promote transit-commuting to offices near rail stops by flexing parking standards, introducing high-quality feeder buses, and initiating workplace incentives such as deeply discounted transit passes. While housing has generally been the focus of transit-oriented development, unless the other end of the commute trip—the workplace—is also convenient to transit, transit will continue to struggle in winning over commuters in an environment of increasingly decentralized employment growth.

Introduction

Transit oriented development (TOD)—compact, mixed-use development around transit stations—has gained popularity as a smart-growth strategy. A national survey recently identified more than 100 TODs across the United States that were self-identified by local transit-agency planners (Cervero et al. 2004). TOD is arguably the most cogent form of smart growth: lay citizens and politicians alike

can relate to the idea that if there is any logical place to target dense, mixed-use development, it is in and around transit stations.

If there is any single aspect of TOD that all sides agree is beneficial to society, it is increased ridership. According to its backers, TOD can relieve traffic congestion, improve air quality, cut down on tailpipe emissions, and increase pedestrian safety in transit-served neighborhoods by coaxing travelers out of their cars and into trains and buses.

To date, TOD's ridership benefits have focused on residential development, with studies generally concluding that residents living near U.S. rail stations are five to six times more likely to commute via transit than the typical commuter in a region (JHK and Associates 1987, 1989; Cervero 1994a; Bernick and Cervero 1997; Lund et al. 2004). The "ridership bonus" associated with TOD residences is mainly a product of self-selection (Cervero et al. 2004). Those with a lifestyle predisposition for transit-oriented living conscientiously sort themselves into housing within an easy walk of a transit node and act on these preferences by frequently taking transit. That is, being near transit and being able to get around via trains and buses weighs heavily in residential location decisions.

While the relationship between living near and riding transit is fairly well understood, less is known about the ridership impacts of working near transit. Self-selection is less likely at play since the ability to commute via transit weighs less heavily in choosing a workplace than a residence. In view of this, is there a discernable ridership bonus associated with transit-oriented working?

The relationship between transit and workplace location is partly important in light of unfolding employment trends. As employment continues to decentralize into areas with meager transit services, increasing reliance on the private automobile can be expected. Past research shows that the trend toward low-density office development partly explains modal shifts to the private car (Cervero 1989; Cervero and Landis 1992; McDonald and Prather 1994). During the 1990s, more U.S. office growth occurred in the loose constellation of multitenant office buildings strung along county and minor roads, what Lang (2003) calls "edgeless cities," than in the compact, mixed-use suburban downtowns, or "edge cities," popularized by Garreau (1991). By 2000, edgeless cities accounted for more total office space than the downtowns of 11 of America's 13 largest metropolitan areas (Lang 2003).

Part of the rationale behind TOD is to channel decentralized growth into a form that is more conducive to transit riding. Most TODs that are taking form outside

of downtown districts, however, have been oriented toward housing construction (Dittmar and Ohland 2004). Single-use (i.e., housing-only) development around transit stations, however, is unlikely to yield significant mobility dividends. Past research shows that station-area residents are far more likely to transit-commute if their workplaces are also near transit (Cervero 1994a), particularly among those working outside of downtown districts who can park for free (JHK and Associates 1989; Cervero 1994a). That is, for suburb-to-suburb commutes, both trip origins and destinations need to be reasonably close to transit if middle-income “choice” commuters are to ride transit in significant numbers. This is very much the Scandinavian model: trains and buses are filled in both directions along transit corridors in greater Stockholm and Copenhagen in large part because *both* housing and job sites are concentrated in and around rail nodes (Cervero 1998).

This article examines the impacts of office development around rail stations on transit mode choice, drawing on a large survey of those working in office buildings in California’s largest metropolitan areas. In addition to studying impacts of building proximity to rail stations on commute mode choice, the effects of workplace parking and policy variables are also probed. Moreover, the influences of factors like trip distance and street connectivity on midday travel choices of those working near rail stations are examined. The article concludes with discussions on the policy implications of the research findings.

Past Research

Many offices experience high rates of transit ridership by virtue of the fact that they are located downtown where levels of transit accessibility are the highest. Outside of downtowns, however, the availability of free parking combined with the sparser and less frequent levels of service sharply erodes transit ridership. In the case of the San Francisco Bay Area, for instance, 49 percent of those working in downtown San Francisco commuted by transit in 2004 compared to under 5 percent of those who worked in nondowntown areas (RIDES for Bay Area Commuters, Inc. 2004).

Evidence on the ridership impacts of rail-oriented office development comes mainly from metropolitan Washington, D.C. and California. Surveys of rail-commuting in metropolitan Washington, D.C. found that nearly 50 percent of those working in offices within 1,000 feet of downtown Metrorail stations rail-commuted. In the case of offices that were comparable distances from the more

suburban Crystal City and Silver Spring stations, the shares were 16 percent to 19 percent (JHK and Associates 1987). Place of residence was a particularly important explainer of whether office workers patronized transit. In the case of the Silver Spring Metro Center, a 150,000-square-foot office tower 200 feet from the Metro-rail portal, 52 percent of workers who lived in Washington, D.C. rail-commuted; among those living in surrounding Montgomery County, Metrorail was used by just 10 percent (JHK and Associates 1989).

Surveys of those working in offices near rail stations in the San Francisco Bay Area in the early 1990s found that around 1 of 10 individuals got to work by transit (Cervero 1994b). Suburban station-area workers were 2½ times more likely to get to work by rail than other Bay Area commuters. As in metropolitan Washington, living near transit made a difference. On average, 19.3 percent of those who lived in a city served by Bay Area Rapid Transit (BART) trains and who worked near a BART station commuted by rail compared to 12.8 percent of those who worked in a similar setting but did not live in a BART-served city. A similar mode split—18 percent—was found among those working at a mixed office-retail air-rights building on the edge of downtown San Diego (Martin 1996). The Bay Area study found office densities around suburban stations had a positive influence on ridership. For every additional 100 employees per acre, rail ridership rose 2.2 percent, on average. Clustering of suburban workplaces around stations is important since as long as office development is geographically close and oriented to rail transit (i.e., within a convenient walking distance), experiences indicate that reasonable shares of workers will commute via transit.

Modal Share Impacts of Rail-oriented Office Development

To examine the modal split implications of office development near rail during this era of “edgeless city” growth, I codirected a study that surveyed workers at 10 predominantly suburban office buildings situated within ½ mile of a rail station in five California metropolitan areas: Los Angeles-Orange County, Sacramento, San Diego, the East Bay (Alameda and Contra Costa Counties) and the South Bay (Santa Clara County) of the San Francisco Bay Area (see Lund et al. 2004, for details). These buildings were chosen, in part, to correspond with the seven rail-oriented office buildings that I surveyed and studied in 1992 (Cervero 1994b), thus providing a time-series perspective. Workers at the 10 office buildings voluntarily completed self-reported surveys on their commute trips and travel during their work hours in the spring of 2003. A total of 877 surveys were received, yielding a

20 percent response rate. The 10 surveyed office buildings were served by three types of rail services: heavy rail in the San Francisco Bay Area (BART) and Los Angeles (Metrorail–Red Line); light rail in San Diego (Trolley), Sacramento (Regional Transit), and Santa Clara County (Valley Transit Authority); and commuter rail serving Orange County (Metrolink). Employment densities of the surveyed office buildings ranged from 8 to 37 jobs per net acre, below the benchmark of 50 jobs per acre sometimes used as a minimum threshold to justify rail transit investments (Ewing 1998).

Ridership Bonus

Based on the survey results, there was a clear ridership premium associated with working near a rail station, at least among Californians in 2003. Rail or bus was the primary commute mode for 18.8 percent of the surveyed office workers. This was nearly three times the weighted average of 6.3 percent of commutes by transit among workers of the seven California counties from which the office-building sample was drawn, based on Part II (place-of-work) data from the 2000 Census Transportation Planning Packages (CTPPs). While having nearly one out of five office workers in fairly low density settings commuting via transit is impressive by U.S. standards, this was miniscule compared to the just over two-thirds of survey respondents who solo-commuted, despite the close proximity of the sampled buildings to frequent peak-period rail services. Around 10 percent of those surveyed arrived to work in a carpool, and just over 3 percent commuted by foot or bicycle.

Interestingly, for the seven recently surveyed office buildings that were also surveyed in 1992, 23.9 percent of workers commuted by transit. This compares to a transit market share of 14.3 percent among the workers of the same buildings surveyed in 1992. A simple difference of proportions comparison reveals this market-share increase is statistically significant at the .01 probability level. Why? It could be that a rail-served office location gained value over time as more and more Californians opted to move to housing near rail stops. Additionally, all large California metropolitan areas experienced employment growth and, correspondingly, worsening traffic congestion during the 1992–2003 period, factors that could also have had a hand in the rising share of transit-commuting among rail-oriented workers.

Aggregating the modal split data for all survey respondents within each office building allowed a simple plot of transit shares as a function of distance to station. Figure 1 shows that work-trip market shares fell with distance in a negative expo-

Figure 1. Ridership Gradient: Transit Share as a Function of Distance of Office Site to Nearest Station

nential fashion. The best-fitting equation, estimated from these 10 data points, took the form:

Estimated proportion of commutes by transit =

$$0.523 - 0.067 \log_e (\text{distance}), R^2 = .678 \quad (1)$$

Notwithstanding the small sample and aggregate nature of the data, the presence of a relatively steep nonlinear slope suggests considerable ridership benefits accrue from clustering suburban employment growth around rail stations, at least in California.

Insights can be gained by examining the two outlier cases with relatively high transit mode shares in Figure 1. Besides lying relatively close to a rail station platform, the two buildings represented by these cases—the California Department of Conservation building in Sacramento (27% transit-commute share) and Great Western Building in Berkeley (17% transit-commute share)—also had what other buildings did not—density, mixed-use environments, and market-rate parking prices. The employment densities of the two buildings—37.6 workers per acre for the Department of Conservation and 20.6 per acre for Great Western—are

much higher than those of the other eight projects. Comparatively high densities translated into comparative high parking costs: both projects charge more than \$100 per month to park. Moreover, there is no parking at the nearest rail stations of either office building.

Station Access and Egress

How did the surveyed rail commuters access stations? Fifty-one percent drove alone to the rail station at the home-end of their trip. Another 6 percent car-pooled. A third walked and the remaining respondents reached stations by bus (7%) or bicycle (2%).

Once surveyed rail users reached their destination station, 78 percent got to work by foot. Most of the remaining surveyees transferred to bus to reach their offices (even though all were less than ½ mile from the egress station).

Trip Chaining

One factor that could have cut into the share of commute trips by transit was the need to make intermediate stops to and from work. Thirty-five percent of the surveyed workers made intermediate stops. Those commuting by private cars were far more likely to chain trips than transit commuters. The main reason for intermediate stops was to pick up or drop off children (27% of trip chains), followed by shopping (21%), personal business (21%), eating (13%), and social-recreation (8%). The need to chain trips underscores the importance of placing multiple uses, such as child-care centers and retail shops, in and around transit stations to enable workers to consolidate trip ends. San Diego Transit, for example, has worked with local planners to site eight child-care centers within ¼ mile of light-rail stations for this very reason.

Influences of Changing Workplaces

Of the 877 office workers surveyed, 102 had changed their workplace location within the past three years to an area served by rail. Among these individuals, 47.1 percent continued to drive alone and 7.8 percent continued to take transit as their “typical” commute mode. Thus, around 55 percent did not change their commute habits after their job site changed to a rail station area. Only 10.8 percent of those who changed workplaces switched from automobile to transit (rail or bus) commuting. Surprisingly, 8.8 percent switched from transit to automobile. This suggests that factors like plentiful parking, which exceeded one space per worker at all but 1 of the 10 sampled office buildings, likely eclipsed the proximity of transit in shaping commuting choice.

Factors Influencing Transit Mode Choice

To explore the influences of workplace policy variables and built environment factors on commuting, a best-fitting model was estimated that predicts whether surveyed office employees took transit to work. Variables entered if theory suggests they belonged in the model (e.g., travel time) or if they were statistically significant and yielded intuitive and reasonable results. Some variables, notably those related to sociodemographic attributes of workers and urban design of workplace areas, did not enter into the best-fitting model because of high multicollinearity. In all, 10 variables related to the density, mixed-use attributes, and street design features of ½-mile rings around each surveyed office were candidates to enter the model, but because of the limited variation in these attributes, none did.

Table 1 presents the best-fitting mode-choice model, estimated in binomial logit form. Longer travel time by automobile over the highway network increased the likelihood of an office worker commuting by transit. While not statistically signifi-

Table 1. Best-Fitting Binomial Logit Model for Predicting Transit-Commute Choice Among Surveyed Office Workers

--	--

cant at the .05 probability level, this variable was included in the model as a measure of generalized cost. Quality of transit service also mattered. As the frequency of feeder bus service at the closest stations to surveyed office sites increased, so did the odds of workers rail-commuting. Consistent with expectations, higher car ownership levels reduced the odds of office workers transit-commuting.

Two variables most easily subject to change that entered the model pertain to employer parking and workplace policies. The probability of office workers commuting by transit fell as the supply of parking relative to workforce size increased. And employer assistance in covering the cost of transit travel, such as the provision of deeply discounted Eco-passes, significantly increased the odds of transit-commuting. It follows that flexing parking standards and providing tax or impact-fee credits to businesses near transit sites that help their employees with transit costs can promote transit-commuting.

Sensitivity Test

A sensitivity test was conducted using the logit model from Table 1 to illuminate the influences of changeable variables—notably, feeder bus service frequencies and workplace policies—on commuting choice. The sensitivity results, shown in Figure 2, are for the typical worker situation, assuming an average commute by car of 30 minutes and one car per household member 16 years of age or more. The figure shows the estimated probability of a surveyed office worker commuting by transit given changes in the three policy variables in the model: frequency of feeder bus services (the covariate on the horizontal axis); whether employers help with transit costs (shown by the solid lines); and parking supplies per worker (shown by the dashed lines). With 25 feeder buses per day, an office setting with 50 percent more parking spaces than workers, and no employer help with transit costs, the model predicts that just 8 percent of office workers near a rail station will commute by transit. At the other extreme, for a worker heading to a station with 400 daily feeder buses who works for an employer who provides transit-pass assistance and provides one parking space for every two workers, the likelihood he or she will commute by transit is 50 percent. Over the range of feeder bus frequencies, the differential in transit-commuting probabilities is 30 to 40 percent depending on how generous employers are in promoting transit (i.e., minimal parking and help with transit costs) or in accommodating the automobile (i.e., ample parking and no help with transit costs).

Figure 2. Sensitivity Test: Influences of Employer Parking and Transit Cost Policies and Feeder Bus Frequencies on Probability of Transit-Commuting Among Office Workers

Midday Travel Behavior

Surveyed office workers were also asked to report on their midday travel (trips made during the workday which began and ended at the workplace). The predominant mode for midday trips was walking, representing 56.7 percent of all journeys out of and back to the surveyed office buildings during work hours. Trip distance had a strong bearing on midday travel. For trips less than $\frac{1}{4}$ mile in distance, 96 percent were by foot. Among midday trips between $\frac{1}{4}$ and 1 mile in distance, 73.5 percent were by walking, 22.6 percent were by private automobile, and just 4.7 percent were by transit. Beyond 1 mile, more than 80 percent of trips were by car, and despite the proximity of rail stations, under 5 percent were by transit. Transit's meager share likely reflects the effects of rail's limited geographic coverage in California cities as well as the curtailment of services during nonpeak periods.

Given that more than half of midday trips made by surveyed office workers were by foot, a choice model was estimated for predicting trips by walking instead of mass transit. Because most midday trips occurred within the vicinity of work-

places, variables related to regional travel times and residential land-use patterns were not considered. A limited set of variables pertaining to travel distance and purpose of midday trips as well as street connectivity near the workplace entered the best-fitting model.

Table 2 presents the logit model that best predicted midday mode choice. All variables in the model were highly significant and the model itself had moderately good predictive powers. The table shows the probability of walking during the midday was higher if the journey was 1 mile or less, consistent with the descriptive statistics previously mentioned. Taking care of job-related business also increased the odds of walking during the midday. Evidently, most out-of-office job-related activities were to nearby destinations, reachable by foot. Lastly, the most relevant policy variable was the level of street connectivity in and around the office site. As the share of intersections within a mile of the office that are four-way or more increases, the odds of walking also rises. Grid street patterns are a hallmark of New Urbanism designs since they provide high levels of connectivity for pedestrians. High connectivity evidently encouraged office workers to walk to midday destinations. The ability to get around in the midday without the need of a car enabled

Table 2. Best-Fitting Binomial Logit Model for Predicting Walk Choice for Midday Trips by Office Workers

--

some workers to commute by transit. If they had to drive to reach midday destinations, odds are they would drive to work to have a car on-site.

Conclusions and Policy Responses

Clearly, a ridership bonus is associated with office development near rail stations in California. This was true in 1992 and even more so in 2003. As congestion levels have worsened over the past decade, more and more office workers are finding it to their liking to take transit to work, notwithstanding the trend toward “edgeless cities” and scattered multitenant office development.

This research found that around one out of five workers in offices outside of large downtowns in California commuted via transit, nearly three times transit’s market share of commutes for all workers in the study regions. Workers were most likely to rail-commute if frequent feeder bus services were available at their egress stations, their employer helped cover the cost of taking transit, and parking was in relatively short supply. Factors like the need to chain trips deterred transit riding, however. Over a third of surveyed workers made intermediate stops as part of their commute trips, and over a quarter of the stops were for dropping off or picking up children. Siting child care centers in the vicinity of transit stations—whether at the home- or work-end of the trip—would no doubt promote rail-commuting among many trip-chainers.

Midday travel choices of surveyed office workers were also examined. Most workers walk to midday destinations, such as restaurants and retail shops, if they are reasonably close to their offices; however if destinations are beyond a mile, the vast majority would take a car. Such dependency on a car for midday trips can discourage office workers to commute by transit, even if a rail station lies near their workplace. This underscores the importance of creating mixed-use environments in and around office sites. Islands of stand-alone office buildings, regardless of how close they are to transit, are unlikely to draw many workers to trains and buses if there is a risk of being stranded in the midday, unable to attend to personal affairs (Cervero 1989).

There is likely little need for public policies to encourage office development around rail stations. Many local municipalities have an incentive to zone for office and commercial development near rail stations in the interest of generating higher property tax receipts. In Southern California, for instance, station areas were found to have 340 percent higher shares of commercial zoning than traditional develop-

ments (Boarnet and Crane 1998). Public policies could help with regard to parking, transit services, and employer incentives. Flexible parking standards that allow below-norm supplies should be considered for all commercial buildings around rail transit stops given the empirical evidence, as shown in this article, that higher shares of worker trips are by transit. Transit's ridership bonus should translate into fewer automobile trips per 1,000 square feet of development and, correspondingly, a reduced need for on-site parking. This research also showed that employer assistance with transit costs matters, even in the case of office buildings close to transit. Beyond the Federal tax credits granted to employers who underwrite the cost of transit-commuting, local governments could consider similar arrangements to further stimulate transit riding. Perhaps public policy-makers can encourage transit-commuting among rail-oriented office workers the most by enhancing both local and regional transit services: the frequency of feeder bus services to stations serving offices as well as comparative travel times by transit were both significant predictors in the models presented in this research.

Policy-makers must not leave it solely to the marketplace to create station-area office environments that are conducive to transit-riding. Regional planning organizations in the San Francisco Bay Area have been very proactive in encouraging transit-oriented housing, such as the Housing Incentive Programs (HIPs) that provide local governments with cash grants (as high as \$2,000 per bedroom) for housing units built within 1/3 mile of rail stations (Cervero et al. 2004). Policy-makers need to be similarly proactive in the case of office development—not so much to encourage transit-oriented offices but rather to encourage site designs, including the arrangements and supplies of parking, and workplace policies, such as employer assistance with transit fares, which promote transit. In the end, concentrating housing near rail stops will do little to lure commuters to trains and buses unless the other end of the trip—the workplace—is similarly convenient to and conducive to using transit.

References

- Bernick, M., and R. Cervero. 1997. *Transit villages for the 21st century*. New York: McGraw-Hill.
- Boarnet, M., and R. Crane. 1998. Public finance and transit-oriented planning: new evidence from Southern California. *Journal of Planning Education and Research* 17 (3): 206–219.

- Cervero, R. 1989. *America's suburban centers: The land use-transportation link*. Boston: Unwin-Hyman.
- Cervero, R. 1994a. Transit-based housing in California: Evidence on ridership impacts. *Transport Policy* 1 (3): 174-183.
- Cervero, R. 1994b. Rail-oriented office development in California: How successful? *Transportation Quarterly* 48 (1): 33-44.
- Cervero, R. 1998. *The transit metropolis: A global inquiry*. Washington, DC: Island Press.
- Cervero, R., and J. Landis. 1992. Suburbanization of jobs and the journey to work: A submarket analysis of commuting in the San Francisco Bay Area. *Journal of Advanced Transportation* 26: 275-297.
- Cervero, R., S. Murphy, C. Ferrell, N. Goguts, and Y. H. Tsai. 2004. *Transit-oriented development in the United States: Experiences, challenges, and prospects*. Washington, DC: Transportation Research Board, TCRP Report 102.
- Dittmar, H., and G. Ohland. 2004. *The new transit towns: Best practices in transit-oriented development*. Washington, DC: Island Press.
- Ewing, R. 1998. *Transportation and land use innovations*. Chicago: APA Press.
- Garreau, J. 1991. *Edge city: Life on the new frontier*. New York: Doubleday.
- JHK and Associates. 1987. *Development-related survey 1*. Washington, DC: Washington Metropolitan Area Transit Authority.
- JHK and Associates. 1989. *Development-related survey II*. Washington, DC: Washington Metropolitan Area Transit Authority.
- Lang, R. 2003. *Edgeless cities: Exploring the elusive metropolis*. Washington, DC: Brookings Institution Press.
- Lund, H., R. Cervero, and R. Willson, R. 2004. *Travel characteristics of transit-oriented development in California*. Oakland: Bay Area Rapid Transit District.
- Martin, J. 1996. *MTS joint development site transit surveys*. San Diego: San Diego Association of Governments, unpublished agency report.
- McDonald, J., and P. Prather. 1994. Suburban employment centers: The case of Chicago. *Urban Studies* 31: 201-218.

RIDES for Bay Area Commuters, Inc. 2004. *Commute profiles 2004*. San Francisco: RIDES.

About the Author

ROBERT CERVERO (robertc@berkeley.edu) is professor and chair of the Department of City and Regional Planning at the University of California, Berkeley. His recent research has included studies on the effects of transit-oriented development on travel behavior in California and elsewhere in the United States.

Predicting the Impact of Demand- and Supply-Side Measures on Bus Ridership in Putrajaya, Malaysia

*Nor Ghani Md. Nor and Abd Rahim Md. Nor,
National University of Malaysia
Ahmad Zainuddin Abdullah, University Putra Malaysia*

Abstract

Putrajaya is a unique Malaysian city from a transport policy perspective because of its explicit goal to achieve a 70 percent share of public transport to its core precincts. A study was recently commissioned with the aim of quantifying travelers' responses to policy measures to ensure effective strategy formulation. This article describes and discusses the methods, results, and policy implications of the study. Econometric estimation results show that improvement in public transport alone is incapable of inducing sufficient modal shift to achieve the goal of a 70:30 split between public and private transport. Although service quality positively influences ridership, modal split is generally not very sensitive to variation in the quality of public transport service. Thus, demand management measures appear to be indispensable as a policy tool to reduce dependence on private transport.

Introduction

Malaysia's new federal administrative capital of Putrajaya¹ is a unique Malaysian city from a transport policy perspective due to its explicit policy goal to achieve a

70 percent share of all travels by public transport to its core precincts (Putrajaya 1997). No other city in Malaysia has a target for transportation modal split, let alone a target to make public transport the overwhelmingly dominant form of transportation. The task confronting the city authority, however, appears insurmountable because this goal entails a reversal of the current modal split of 15:85 between public and private transport. Factors contributing to the domination of private transport as the preferred mode of travel in Putrajaya include the provision of a high quality road network with generous road space, the availability of ample parking spaces provided free of charge, and the generally modest cost of owning and operating private vehicles. In addition, poor public transport services further encourage the use of private vehicles.

In its effort to achieve the desired modal split, the city authority has been contemplating the implementation of two broad measures, namely, improving public transport service and imposing penalties on private vehicle travels. To ensure effective strategy formulation, a study was commissioned to model users' travel behaviors with the goal of quantifying their response to a proposal for public transport improvements and demand-restraining measures. Subsidizing public transport services is one of the options the authority is willing to consider to improve service level. Examples of potential demand-restraining measures include the introduction of road pricing schemes for private vehicle travels, a restrictive parking policy that combines limitation on the amount of parking spaces with high charge rates, and private vehicle ownership restriction by ownership tax. Some of these measures have been implemented rather successfully in London, Singapore, and several other European cities.

This article first provides an overview of the public transport system in Putrajaya and then proceeds to discuss the methods that have been adopted in the study, the results of the econometric estimation and simulation of the mode choice models, and the policy implication of the various findings.

Overview of Existing Public Transport Services

Currently, intercity public transport services in Putrajaya are served by several bus companies, which carry passengers from Kuala Lumpur and major towns in the surrounding areas. Three private bus operators serve these external routes, while another private bus company operates intracity bus services, ferrying passengers within Putrajaya. Several contract buses, mostly transporting government ser-

vants working in Putrajaya from towns located at the outskirts of the city, are also in operation. Besides buses, the track-based KLIA Transit provides rail transport services that link KL Sentral in Kuala Lumpur and the Kuala Lumpur International Airport. Figure 1 provides a general overview of the major bus routes and highways in Putrajaya.

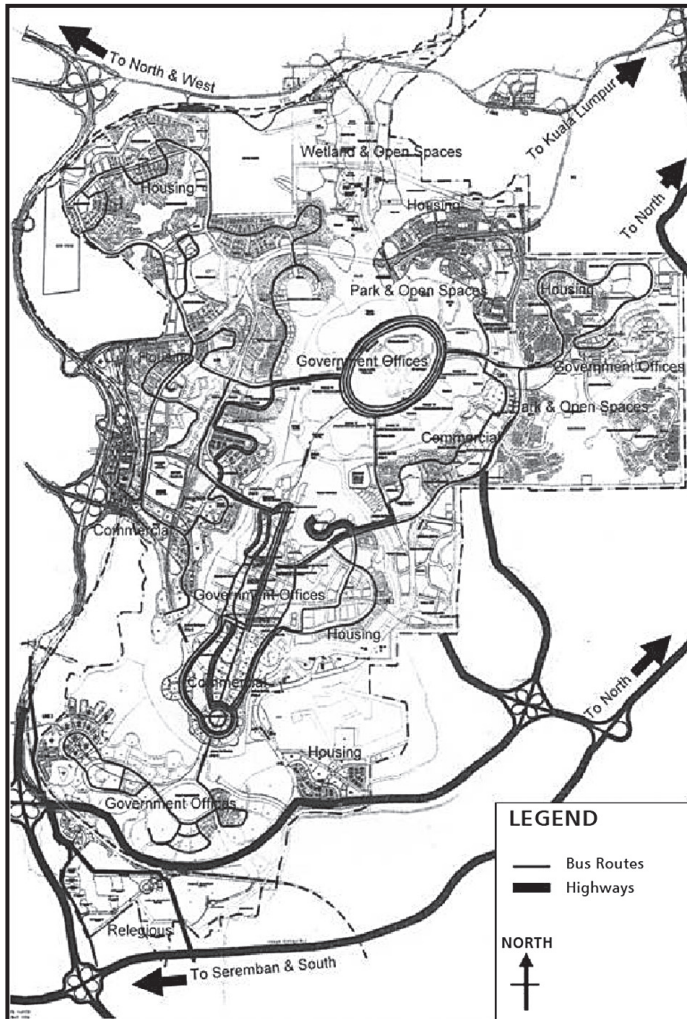


Figure 1. Major Bus Routes and Highways in Putrajaya, Malaysia

The existing public transport system lacks choice, quality, and availability. The intracity bus company operates only 14 buses to transport passengers from residential areas in the periphery to offices and commercial centers in the core area. Generally, these buses have poor service frequency with an average of 2 per hour, even during the morning and afternoon peak periods. The buses are of standard high-floor design with no provision for the disabled and elderly. With limited rolling stock, bus service has also been unreliable. Intercity rail services are provided by the Express Rail System (ERL) and the Keretapi Tanah Melayu Berhad (KTMB) rail commuter system. However, both systems can at best be described as inadequate. For example, the KLIA Transit service provided by the ERL stops at a station quite far from the city center, forcing passengers to take transfer bus rides.

Survey Methodology

The study adopted the stated preference (SP) survey method to solicit the required information to model mode choice behavior. Using elasticities obtained from studies using actual market (revealed preference) data is another option that can be considered. In the course of designing the study methodology, the SP method was deemed preferable for two main reasons.

First, although revealed preference estimates are based on real conditions in which individuals consider the internal costs, benefits, and consequences of their choices, the major weakness of the method is its reliance on historical data. This reliance poses one major difficulty to the current study. Increasing public transport ridership from 15 to 70 percent is expected to require a change in traveling cost and/or service level so substantial that its goes beyond the range of historical experience observed in previous revealed preference studies. The question becomes whether the estimates of the impact on ridership based on relatively small variations in costs and service levels found in these studies is reliable. SP surveys, on the other hand, can be designed to allow for estimation of behavior beyond the range of historical experience.

The second major reason for selecting the SP method is that reliable studies on fare, service, and cross elasticities from the developing or third-world settings are rare. Most elasticity estimates are obtained from studies conducted in the developed countries (see Litman 2005 for an excellent review). Of those studies conducted in developing countries, all were devoted mainly to determining the response of ridership to increase in public transport fare or travel cost. By and

large, it is also fair to argue that these studies (some of which are reviewed by Oum et al. 1992) tend to be outdated.

Despite the above-mentioned advantages, the SP method is known to suffer from several weaknesses. Chief among them is that the approach is not based on the actual market, so respondents may be providing hypothetical answers to hypothetical questions and would not actually behave in the manner stated in the experiment. In many cases, hypothetical choices may not reflect budget and other constraints on behavior. Multi-attribute choice tasks might also place a cognitive burden on interviewees since there is a limit to how much information they can process while making a choice. This, in turn, will cause both learning and fatigue effects, leading to sometimes irrational choices. Hence, the complexity of a choice experiment in terms of the number of choice sets and/or the number of attributes in each choice set may effect the quality of the responses and would require some trade-off between the complexity of the choice experiment and the quality of the responses (e.g., Schkade and Payne 1994).

In a developing country setting, it may be argued that these problems are, in fact, further accentuated because of the respondents' lack of formal education and low socioeconomic status. Fortunately, this is unlikely in Putrajaya because the levels of formal education and socioeconomic status are significantly higher than other parts of the country. Other technical objections to the SP method include design bias in the way information is put across to respondents, strategic bias when respondents may think that they can influence the course of real events by making a particular pattern of choice, and social desirability bias, where respondents attempt to reflect themselves in a favorable light with respect to some social norms.

In eliciting mode preferences, the study also tries to incorporate principles and discussion on appropriate instrument and survey methods as in Louviere (1998), Diamond and Hausman (1994), and Hanemann (1994). A review of existing literature reveals that significant travel attributes that affect mode choice are already well known and, hence, repeatedly used in many prior studies. The present study adopted these known attributes, namely, in-vehicle time (travel time), headway, and out-of-pocket financial cost (fuel, fare, toll, and parking charges). In designing the questionnaire, attempts were made to ensure that choices offered to the respondents were as realistic as possible and that the initial attribute levels matched the characteristics of current modes of travel as closely as possible. In the interest of realism and since there are virtually no parking and road-toll charges,

respondents were also reminded that the financial costs of using private vehicles can vary over a relatively wide range of values because of a possible introduction of road-pricing and/or parking charges.

The range of choices and the levels of variation were further refined using focus group techniques. Focus group sessions were conducted to ensure that the selected attributes and their corresponding levels could be combined in a credible manner (Layton and Brown 1998). Participants were also encouraged to provide definite feedback on the complexity and realism of the survey instrument.

Five sets of survey instruments were eventually drafted, one set for each of the five broad travel purposes present in Putrajaya. The travel purposes were work commute from within Putrajaya, work commute from outside Putrajaya, official business with government departments, social/shopping, and tourism/visits. The questionnaire sets were essentially very similar except in the scenario-building section in which the description was customized to suit different trip purposes. Table 1 shows the attributes and attribute levels that were finally incorporated into the questionnaire instrument for the full survey. "Levels" refer to the different level of values that the respective attributes assume in the choice experiments incorporated in the questionnaire set. In this study, financial cost assumes four levels, while in-vehicle time and headway each assumes three levels. Only three levels are offered for in-vehicle time and headway (hence, blanks under Level 3)

Table 1. Attributes and Attribute Levels

*Exchange rate: US \$1= RM3.65 (April 2006)

to reduce the number of choice experiments presented to the respondents. Due to the popularity of motorcycles in Malaysia, the three modes offered were car, motorcycle, and public transport.²

The sampling process attempted to capture sufficient numbers of respondents for each trip category to reflect the population of trip makers. At the beginning of an interview session, respondents were briefed on the purpose of the interview and the expected amount of time required to complete a questionnaire set. Equally important, a thorough description was given to the respondents regarding the types of public transport services being considered in the choice experiment. This was done to avoid the need to incorporate a relatively large number of service attributes and levels. Respondents were told to consider a high quality public transport (bus) service with the following features: clean and comfortable, air-conditioned, ample seating capacity, conveniently located as well as covered bus stops/terminals, provision of park-and-ride facilities, punctual, safe, courteous drivers, and an option for electronic/manual fare collection. The description was provided with some details to encourage respondents to dispel currently held negative perceptions about public transport.

The full survey was conducted in September and October 2003. The total number of respondents for the survey was 2,000; however, only 1,943 were deemed usable for further analysis. The remaining responses were discarded mainly due to incomplete responses.

Table 2. Distribution of Respondents by Trip Purpose

Mode Choice Modeling

It is assumed that the mode choice for a trip maker is a reflection of his preference, and the choice can be predicted if all variables pertinent to this choice are known and measurable. Probabilistic choice models can then be estimated to link the probabilities that the different alternatives will be selected to the set of pertinent explanatory variables (Horowitz 1995). Three of the trip purposes (work commute from within, work commute from outside, and official business with government departments) were combined into one business trip category. A multinomial logit model was estimated for each trip purpose and then used as the basis for predicting mode split for different policy choices.

Results

Results of the regression estimation are presented in Table 3. The coefficients for the financial cost variable are of the correct sign and generally statistically significant. Although the coefficients for headway and in-vehicle time mostly carry the correct sign, they are not statistically significant, suggesting that users are not particularly affected by changes in public transport service quality. This observation provides a very important policy implication between the relative efficacy of demand and supply measures, as discussed in the next section. The coefficients for financial cost, headway, and in-vehicle time are mostly negative, implying that the proportion of trips accounted for by public transport increases as the spread in generalized cost, waiting time, and travel time between private and public transport increases. The relative impact certainly differs across factors but is consistent with the fundamental economic principle that demand for public transport should vary inversely with cost (financial or otherwise).

The signs for the gender coefficients are negative and highly significant for business trips (and for both car and motorcycle), supporting the notion that, because of the generally lower occupational/income level of women and alleged bias in local custom against women riding motorcycles, there is greater certainty in the statistical sense that proportionally more women choose public transport compared to men. The results are rather mixed for the other two trip purposes. The coefficients for income are also as expected (all negative for car and generally positive for motorcycle), indicating that relative to the control group of higher income individuals, people in lower income categories are more likely to choose motorcycles and less likely to choose cars compared to public transport.

Table 3. Estimation Results of the Multinomial Logit Model by Trip Purpose

Discussion and Policy Implications

An important policy question for the Putrajaya authority is whether it is sufficient to rely only on improvements in public transport to achieve the desired 70:30 goal. The initial reluctance on the part of the authority to consider demand-restraining measures stems from the notion that since Putrajaya is the federal administrative capital, any penalty imposed on private vehicle use may be construed as the government being insensitive to the wishes of the public. This perception is expected to be further heightened by the fact that Malaysians are generally not used to demand-restraining measures. However, results of the analysis suggest that supply-side policy through improvement in public transport alone is likely to be inadequate. Under the improved scenario, headway and in-vehicle time for bus are assumed to be at 5 minutes and 15 minutes, respectively (lowest values in the

choice set). Other bus service improvements are as described to respondents at the beginning of the interview (i.e., improved bus design and amenities; enhanced bus stops and terminals; park-and-ride facilities; punctual, safe, courteous drivers; and electronic/manual fare collection). Results of further computations (Table 4) reveal that improvements in public transport will increase public transport ridership from the current 10 to 15 percent to about 30 to 40 percent, depending on trip purpose. This figure is nowhere near the target of a 70 percent share of public transport use. However, although headway and in-vehicle time are the only two service characteristics presented in the choice experiment, the increase in ridership cannot be exclusively attributed to improvements in the two characteristics since the respondents were stating their choices within the context in which some other general improvements in bus service had already been assumed.

**Table 4. Mode Shares by Trip Purpose
(Improvement in Public Transport Only)**

Having found that improvement in public transport alone is inadequate, further simulation is performed to determine the required financial disincentive to switch sufficiently large numbers of users to public transport. Table 5 provides the magnitude of the required financial disincentive by trip purpose and vehicle type to achieve the 70:30 split. To provide some perspective, the required financial disincentives (say new toll and parking charges) are equivalent to between a 100 to 300 percent increase in the current out-of-pocket traveling costs. As a policy tool, such a steep increase appears to be unrealistic for immediate implementation because it is very likely to be politically unpopular. However, increases in penalties for private vehicle travel may be introduced in stages over a longer period of time along with improvements in the public transport system.

Table 5. Summary of Required Incentive/Penalty (RM) to Induce 70:30 Split between Public and Private Transport

Separate simulation results also show that worktrips from outside Putrajaya require higher absolute incentives or penalty compared to worktrips originating from within Putrajaya to realize the same degree of mode switch from private to public transport. One reason for this observation is that for the same amount of absolute financial disincentive, the impact on trip costs (both in terms of money and time) is proportionally lower for those traveling from outside Putrajaya compared to those from within the city since trip cost is a function of traveling distance. Such a divergence can complicate the implementation of demand-restraining measures because the scheme must be capable of differentiating and charging the two groups of commuters. One possible solution is to set up an external cordon for charging commuters from outside Putrajaya and enforce parking charges for both internal and external users. The difference in the amount required to deter external users will be picked up by the external cordon charges.

Car users on social and shopping trips are willing to pay the most to use private transport relative to other users. This is probably due to the occasional nature of their trips and convenience of carrying purchased items and traveling in a group with other family members for shopping and social trips by private vehicles.

Any pricing measure on cars (or motorcycles) must take into account not only the impact of relative cost and attractiveness of the mode compared to public transport, but also to motorcycles (or cars). For example, increasing the cost of using a car relative to public transport will not only switch users to public transport but also to motorcycles. Hence, pricing measures should not be targeted on car users in isolation (however attractive it may be from the social perspective). Mode switching from cars to motorcycles instead of to public transport may render the impact of increasing the cost of car use less effective. This is especially important in light of the obvious temptation to leave motorcyclists alone for equity reason when it comes to pricing measures to avoid “harming the low-income group.”

Since imposing penalties on motorcyclists is unavoidable, affordable public transport must be made accessible to switching motorcycle users, particularly those from the lower income group for equity reasons. This can be done through a fare subsidy wholly or partly financed by toll or parking collection on individuals who continue to use private transport.

Finally, calling for financial penalties on private vehicle use may be a delicate option to pursue as it entails potential political ramifications. A strong political will on the part of policymakers is required to realize the transport objective. This policy will, however, become more palatable to the traveling public if a high quality yet affordable public transport system is put in place. When the two measures are coupled together, the increased cost of transport will be less of an issue since those users having to switch to public transport will then have access to an affordable public transport system. Gradual introduction of financial disincentives to private vehicle travel is also likely to be more politically palatable.

Summary

This article describes methods and results of a study conducted in Putrajaya, Malaysia, to induce large numbers of users to public transport. Results from the stated preference survey and the subsequent mode-split modeling and simulations suggest one major policy conclusion. Improvement in public transport alone appears to be incapable of inducing sufficient mode shift in favor of public transport to achieve the overriding objective of 70:30 split. It must be recognized, however, that simulation results clearly indicate that improvement in service quality does increase public transport use by generating a 20 to 25 percent increase in ridership. Since the current public transport fare is already low, lowering the transit fare (along with improvements in public transport service) is also unlikely to induce the desired shift because the cost difference between public and private transport will still be small. Thus, demand-restraining measures, such as cordon pricing and parking charges, appear to be indispensable as a policy tool to achieve the desired goal.

Endnotes

¹ Putrajaya, which is situated 25 km south of the capital city of Malaysia (Kuala Lumpur), occupies a total area of 4,932 hectares and is divided into 20 precincts

(Putrajaya 1997). When fully developed in 2012, Putrajaya is expected to have a night-time population of 330,000 and provide 254,000 job opportunities.

² The current modal split is 70 percent for cars; 15 percent, motorcycles; 15 percent public transport.

References

- Diamond, Peter, and Jerry Hausman. 1994. Contingent valuation: Is some number better than no number? *Journal of Economic Perspectives* 8(4): 45–64.
- Hanemann, Michael. 1994. *Contingent valuation in economics*, Berkeley, CA: Department of Agricultural and Resource Economics, University of California.
- Horowitz, Joel. 1995. Modelling choices of residential location and mode of travel to work. In Susan Hanson, ed., *The Geography of Urban Transportation*, 2nd ed. New York: The Guilford Press.
- Layton, David, and Gardner Brown. 1998. *Application of stated preference methods to a public good: Issues for discussion*. NOAA Workshop on the Application of Stated Preference Methods to Resource Compensation, Washington, DC. June 1–2.
- Litman, Todd. 2005. *Transportation elasticities: How prices and other factors affect travel behavior*. Victoria, Canada: Victoria Transport Policy Institute.
- Louviere, Jordan. 1998. *Analyzing decision making: Metric conjoint analysis*. Newbury Park, CA: SAGE Publications.
- Oum, Tae Hoon, W. G. Waters II, and Jong-Say Yong. 1992. Concepts of price elasticities of transport demand and recent empirical estimates. *Journal of Transport Economics* (May): 139–154.
- Putrajaya. 1997. *Putrajaya review of the master plan* (March).
- Schkade, David, and John Payne. 1994. How people respond to contingent valuation questions: A verbal protocol analysis of willingness to pay for an environmental regulation. *Journal of Environmental Economics and Management* 26(1): 88–109.

About the Authors

NOR GHANI MD. NOR (*norghani@ukm.my*) obtained a Ph. D. in economics from Michigan State University in 1996 and is currently an associate professor and head of the doctoral program at the Faculty of Economics and Business, National University of Malaysia. He teaches microeconomics and transportation economics at both undergraduate and graduate levels at the university.

ABD RAHIM MD. NOR (*rahim@ukm.my*) has a Ph.D. from the University of Sheffield, United Kingdom. He is an associate professor at the Faculty of Social Sciences and Humanities, National University of Malaysia, where he teaches transport geography. In addition, he provides transportation consultancy services to corporate and public organizations.

AHMAD ZAINUDDIN ABDULLAH (*ahmadz@econ.upm.edu.my*) obtained a Ph.D. from University Putra Malaysia. He is a lecturer at the Faculty of Economics and Management, University Putra Malaysia, where he teaches industrial economics and actively conducts research activities.

Smart Bicycles in an Urban Area: Evaluation of a Pilot Scheme in London

*Robert B. Noland and Muhammad M. Ishaque,
Imperial College, London*

Abstract

Automated or smart bicycle systems are seen as a way to enhance mobility and provide a convenient access and egress mode for public transport. This article summarizes an evaluation of a pilot system that was introduced in the London Borough of Hammersmith and Fulham in August 2004. Underground and commuter rail stations, as well as a heavily-used bus network, serve this densely populated area of London. A survey of users was conducted and data were collected from actual use of the system. Analysis of these data provided some insights into the capabilities of these types of systems to enhance existing public transport services. In particular, it was found that the potential of the system lies primarily with the leisure and recreational market and with providing links to public transport stations. The pilot included “sponsored” nonpaying users who tended to use the system more for commuting and utilitarian trips.

Introduction

Bicycles, now recognized as an integral component of a good public transport system, are a convenient access mode to many rail and metro systems. Use of bicycles increases the ability to draw customers from a wider area. Bicycles are also frequently allowed onto public transport systems, providing egress from destina-

tion stations and enhancing customer mobility. Bicycles can also reduce the need for extensive access and egress service from stations, lessen congestion on existing bus routes, and reduce the need for car parking at stations. The key drawback is the ability to take bicycles onto public transport during peak travel periods when passenger congestion is present. An alternative is to provide bicycle rental facilities at stations, but labor costs associated with this can be high.

A new approach is to automate the rental process. This article evaluates OYBike, an automated (or smart) bicycle pilot scheme that was introduced in the London Borough of Hammersmith and Fulham (LBHF) in August 2004. This program was envisioned as potentially providing enhanced mobility options for local residences and for those employed within the borough. It was also seen as both an alternative to public transport, mainly by shifting some trips from the bus network, and as a complementary mode, for both access and egress from Underground and rail stations.

Implementation of smart bicycle systems is becoming increasingly common. For example, one of the more successful programs, the Call-a-Bike system in Germany (<http://www.callabike-interaktiv.de>), is operated by the German National Railway. This system extends existing bicycle rentals that have long been offered at rail stations. Another new scheme, Vélo'v (<http://www.velov.grandlyon.com>), currently running in Lyon, France, is heavily subsidized by the City and is geared at providing mobility within the city, similar to the objectives of the pilot program evaluated here.

Evaluation of the London-based scheme sought to analyze the travel patterns of users (e.g., what type of trips were being taken with the bicycles and how they interacted with the public transport system). The analysis also evaluated the market potential of expanding the scheme into other parts of the Greater London area. Actual usage data for one full year of operation were analyzed. An analysis of scheme costs and maintenance issues was also conducted.

DeMaio and Gifford (2004) previously provided an overview of smart bicycle systems in existence in 2004. OYBike was not yet in use when their review was conducted. Their research evaluated the efficacy of such a system in the United States, as most existing systems are in Europe. Our aim is to provide some quantitative evidence on how these systems actually work within the context of a densely populated urban area with a high-quality but overcrowded public transport system.

As in many other places around the world, London transportation planners are seeking ways to reduce car use. Public transport has played an important role in London, where bus usage has increased by more than 31 percent since 2000 and various initiatives have substantially increased bus service (Transport for London 2004a). London boroughs are required by the Mayor's Transport Strategy to develop plans for increasing bicycle use (Greater London Authority 2001). About 2.5 percent of worktrips involve a bicycle, and usage is reported to have increased substantially since 2000. Counts of Thames River bicycle crossings in Central London have increased by 40 percent in five years (Transport for London 2004b). Thus, there is significant interest in finding ways to increase and accommodate bicycle usage.

The article begins with an overview of the technical details of the OYBike system (more details are available at www.oybike.com). We then describe the pilot scheme as implemented. Actual usage data and responses from user surveys are discussed. Results of the analysis and conclusions are also presented.

OYBike Technology

OYBike is an innovative approach to bicycle rental. The system, a network of street-based rental stations, operates from 6:30 AM to 6:30 PM. Bicycles can be rented using a mobile phone and returned at later hours.

Bicycles are secured to automated locks placed on bicycle stands with cables (see Figures 1 and 2) and attached to Sheffield or "hitching post" style bicycle racks. Each bicycle stand is equipped with a specially-developed electronic lock with a keyboard and LCD display. The lock holds the cable secure until the bicycle is rented and released. Users are given unique PIN codes through their mobile phones via text messaging to both release and return the bicycle. The duration of each hire (from pick-up to drop-off) is monitored by the system, and the user's account is billed and debited accordingly.

An initial registration fee of £10 (about US \$17) is charged and the hire costs start at 30p (\$0.51) for 15 minutes. The maximum charge for a full-day rental is £8 (\$13.60) (for each 24-hour period). Fares are set so that short trips of 30 minutes or less are relatively cheap, but charges increase thereafter. The flat rate for a full-day rental is relatively inexpensive per hour of use compared to shorter time periods. Rentals of more than 30 minutes and up to 3 hours garner the highest hourly rate, at £2/hour (\$3.40/hour). Thus, the current charging regime favors either very short-



Figure 1. OYBike Locking Station



Figure 2. Close-Up of Automated Locking System

term or full-day usage. Table 1 outlines the rate schedule as of December 2005.

Table 1. OYBike Price Schedule

Rental stations are established at key originating and destination travel zones (e.g., Underground stations, public buildings, car parks). About 25 rental stations were operating in LBHF during 2005.

The bicycles, equipped with a basket to allow users to carry small items, have been designed for durability and visibility—each bicycle is bright yellow. They also have an area for advertising space, which is an additional source of revenue for the system. The bicycles' hydraulic drive system minimizes maintenance problems associated with traditional chain-based drives.

The OYBike Pilot

The pilot scheme took place in LBHF, which is located to the west of Central London outside of the congestion-charging zone. LBHF is a densely populated area, primarily residential but with various employment centers scattered throughout the borough. Among the employers in the area is the British Broadcasting Company (headquarters and studios), located in the north of the borough. The central area is around the Hammersmith Underground multimodal station. The south side of the borough is bordered by the Thames River and is the location of the London Wetlands Centre, the primary visitor and tourist attraction within the borough. The local authority was approached to work with the project due to the compactness of the borough, high levels of cycling activity, and a relatively well-developed bicycle network with good bicycle parking facilities (more than 1,000 bicycle racks for public use).

The borough, traversed by the Piccadilly, District, Hammersmith and City, and Central Underground lines, has a dense bus network and several commuter rail stations. As in most central areas of London, public transport is the primary mode of transport. Car use is also heavy, partly due to the entry to the M4 motorway, a major route to the west and to Heathrow Airport. Household car ownership in the borough stands at 51 percent (Ball and Brooks 2004).

The OYBike system was made available for public use on August 22, 2004; the first registration for the service took place on August 23. This research evaluation encompasses one full year of usage, with data collected until August 21, 2005. The beginning of the pilot in late August hampered the early start-up of the system, as weather conditions were less favorable for bicycle use as the autumn months approached. About 25 locking stations were scattered throughout the borough, with 70 bicycles available in total.

In addition to public usage, OYBike arranged for several companies and the local authority to be “sponsored users” of the system. Sponsored users were given free access to the bicycles. This evaluation examines both public and sponsored use.

Survey of Existing Customers

In early September 2005, one year after the start of the pilot, an on-line survey of existing customers was conducted. Registered users who responded to an email request to fill out a web-based questionnaire were offered a usage credit of £10. Of 209 registered and sponsored customers who were emailed, 46 full questionnaires were used for the analysis. Given the size of this response rate, one should bear in mind that this sample is potentially biased. Users most satisfied with the system would be more likely to respond, given that the incentive to complete the questionnaire was a £10 credit for future use of OYBike. Clearly, those dissatisfied with the system or with no intention to use it again would be less likely to respond to this type of incentive.

Demographics

Of the 46 respondents, 50 percent resided in the borough and 35 percent lived elsewhere in London. The remainder lived outside of London or overseas. Most respondents also work in London (63%), while a smaller fraction work in LBHF (22%). A small fraction was unemployed or retired.

Thirty-three percent of the respondents were women and 67 percent were men. Of those living in LBHF, 44 percent were women and 56 percent were men. Of those living outside the borough, 84 percent were men. The largest age group was those of age 26–35 years, accounting for 61 percent of the sample.

Reported Travel Behavior

Very few respondents (7%) normally travel to work or school using a car, as shown in Table 2. Forty-three percent of respondents commute via public transport, mainly the Underground. A large percent normally commute on a bicycle (30%). This should not be too surprising, as we would expect those who currently use bicycles to be more interested in at least testing out the system.

Table 2. How Do You Normally Travel to Work or School?

The stated purposes of trips using OYBike are shown in Table 3. Leisure and recreational trips account for the major uses. Commuting and other utilitarian trips represent about one-quarter of all trip purposes. Those living outside of LBHF have a slightly higher share of recreational trips (74%), compared to 63 percent for local residents, suggesting that visitors to the borough are more likely to use the bicycles for recreation.

Despite this high reported recreational use of the bicycles, many respondents noted that the trips they took are substituting for public transport trips (Table 4). This accounts for 34 percent (coming from buses and the Underground). A large share (21%) would have previously walked, and these users likely reduced their travel times. Twenty-three percent would not have previously made the

trip. These may be recreational trips, but clearly this shows a benefit in allowing increased mobility for these users. Only 6 percent shifted from using a car. This is a surprisingly large number given the type of trips that would be substituted, and shows potential environmental benefits from the system.

Table 3. When You Use OYBike, the Purpose of Your Travel Is Mainly...?

**Table 4. The Journey(s) That You Take with OYBike
Were Previously Taken By...?**

Of particular interest from a transport policy perspective is whether the bicycles are used in combination with other modes of travel (Table 5). Most users, especially those living in LBHF, walk to the OYBike locking station (61% in total and 78% of LBHF residents). Only 37 percent of non-LBHF residents walked to the locking station. Twenty-six percent used rail or the Underground previously. While this is relatively small, it does suggest some ability for the bicycles to be an egress

Table 5. Do You Use a Bus, Rail, or the Underground as Part of Your Journey with OYBike?

mode away from the station. Likewise, a small percent (13%) use OYBike to access the Underground. Analysis of usage data revealed that 40 percent of all paid trips began or terminated at locking stations located outside Underground stations. The convenience of OYBike as an egress mode is further highlighted by examining why users do not use their own bicycles. Of 24 respondents reporting that they own a bicycle, one-third use the OYBike service because of its convenience in conjunction with the Underground.

Perceptions of the OYBike System

In trying to understand system usage, it is helpful to learn about respondents' experiences using OYBike and, in particular, any specific problems that they may have encountered. A series of questions investigated these issues.

Table 6 presents results from questions regarding issues and weaknesses in the current design of the system. In particular, the need to make a phone call and the difficulty of the locking system were of concern to many respondents. More than one-third also cited the overall maintenance of the bicycles. Surprisingly, cost was not an issue for the majority of respondents.

The locking system was also highlighted in responses to the question about problems with the system (Table 7). Twenty-six percent of respondents reported having problems with the locking system. Only 28 percent reported no faults with the bikes or the system as a whole, suggesting that maintenance issues need to be addressed. The gearing system, in particular, seems to be a source of problems.

Despite these problems, 78 percent of respondents were either satisfied or very satisfied with their OYBike travel experience. Only 11 percent reported levels of dissatisfaction, implying that the system is quite positive, although as previously

Table 6. From Your Experience of Using OYBike, Is There Anything You Are Concerned About? (Multiple responses)

Table 7. While Using an OYBike, Have Any of the Following Ever Been a Problem? (Multiple responses)

stated, the survey respondents may have had a more positive view than those who did not respond.

Thirty-four percent reported that the major reason for trying the system was to experience and test it, suggesting that the system’s novelty was one of its key attractions. Another major reason was the desire to use a bicycle occasionally because they do not own one (30%). Not having to worry about finding secure

parking for the bicycle and saving time compared to other modes of transport were the other main reasons cited (each by 26% of respondents).

Usage Evaluation

Actual bicycle usage was evaluated by analyzing data captured when bicycles are rented and returned. Information was available on a total of 214 trips made by 168 registered users. This is clearly a very small sample and results of this analysis should be interpreted with this in mind. In addition to registered users, trips by 18 sponsored users are also evaluated.

Analysis of Trips and Weather Patterns

The rollout of the system in late August hampered a quick start-up. Frequency of monthly registrations follows a pattern that is expected from the London climate. Figure 3, which charts new registrations by month, clearly shows that interest in the system was very low during months when weather and lighting conditions are poor.

Figure 3. Number of Registrations per Month

Weather conditions appear to play a key role in the usage of OYBike. We explore this relationship in more detail by examining weather data obtained from the UK

Met Office for the weather station at Heathrow, the nearest weather station to LBHF. Data was obtained for daily weather conditions from August 2004 to August 2005.

We used data on the cumulative percent of days for the maximum temperature, quantity of rainfall, and hours of sunshine. All these factors can be hypothesized to be correlated with bicycle usage. We would expect that higher temperatures would increase bicycle usage, while more rainfall and less sunshine would reduce it.

Figures 4–6 examine the relationship between these weather variables, based on monthly averages and the number of trips taken on OYBike. There is a distinct relationship between average maximum temperatures for each month and total usage. This relationship also holds for the total hours of sunshine in a given month. Rainfall appears to have a negative effect on usage. In particular, usage was relatively high in September 2004 when rainfall was low, compared to October 2004. Temperature has a more important effect in spring and summer months, while rainfall appears to dampen usage.

Figure 4. Number of Trips and Average Maximum Temperature

Figure 5. Number of Trips and Total Monthly Rainfall

Figure 6. Number of Trips and Average Monthly Hours of Sunshine

The monthly means shown above may hide more interesting effects in the data. Figures 7–9 plot the weather variables against the cumulative number of paid trips taken. Only 10 percent of daily trips were taken on days when the temperature did not exceed 15°C, and 50 percent of daily trips were taken when the maximum daily temperature exceeded 20°C, suggesting that higher temperatures do play a major role in increasing usage. The effect of rainfall is more pronounced, as shown in Figure 8. Days with 0 mm of rainfall account for nearly 70 percent of paid trips. Conversely, a clear pattern emerges of a much smaller percent of total trips on days with significant rainfall.

Figure 9 shows the cumulative percent of trips related to number of hours of sunshine (i.e., a measure of seasonality and cloud cover). This appears to have little effect as the relationship is nearly linear. About 50 percent of cumulative trips were on days with about 0–8 hours of sunshine, while 50 percent were on days with 8–16 hours of sunshine.

Figure 7. Maximum Daily Temperature vs. Cumulative Percent of Paid Trips

Figure 8. Daily Rainfall vs. Cumulative Percent of Paid Trips

Figure 9. Sunshine Hours per Day vs. Cumulative Percent of Paid Trips

Analysis of Likely Leisure and Commute Trips

Analysis of the on-line user survey suggested that recreational and leisure trips were a major market for the bicycles. We examined the usage data to speculate about various patterns in usage that may support this case. The weekly variation indicates that about 51 percent of all usage occurs on weekends, which points to the usage of the system for mainly leisure purposes. Weekend trips also tend to be much longer in duration, which would be consistent with leisure and recreational use of the bicycles rather than use for short utilitarian trips. Figure 10 displays results for number of trips by day of week and the length of the rental.

Figure 10. Number of Trips vs. Day of Week and Length of Hire

The hourly variation in usage also shows that, on weekends, bicycles are hired at mid-day. A more constant rate of hiring occurs on weekdays, including during morning and afternoon peak travel periods. This suggests that, while weekday trips

may be for commuting and other utilitarian purposes, weekend trips are likely more focused on leisure and recreation.

This interpretation of the usage pattern can be partially confirmed by linking the user survey with actual bicycle usage. The five users claiming that their primary use was for commuting had a total of 18 trips (14 by 1 user, 1 individual took 0 trips). Most of the users claiming their primary purpose was commuting took trips on weekdays. While seven of these were at mid-day (Table 8), those that were in the morning and evening hours were likely commute trips, providing some confirmation that users were reporting their trip purposes accurately.

**Table 8. Distribution of Checkout Times for Trips
Based on Reported Trip Purpose**

This is further confirmed to some extent by examining the 32 respondents reporting a primary trip purpose of recreational and leisure trips, of which 26 respondents actually took 42 journeys. We see more of a mid-day pattern to their usage as well as much more weekend usage (Table 8). This suggests that the weekend pattern of usage represents recreational and leisure trips.

Further analysis of stated leisure versus commute purposes shows that a primary source of new trips generated by OYBike was for leisure purposes. Those taking trips they would not have otherwise made were trips likely made for leisure purposes (Table 9). Commute trips, on the other hand, seem to have primarily replaced public transport trips.

Table 9. When You Use OYBike, the Purpose of Your Travel Is Mainly...?

Analysis of Frequency of Usage

Most registered customers used the service once and almost 26 percent are yet to experience their first ride on the system. Only 8 of a total customer base of 168 have made more than 4 rides, the highest frequency being 14. Repeat usage is not high, which may suggest some dissatisfaction with the system after initial usage or which may be due to some users trying out the system for its novelty. Those who use the system more than once tend to be weekday users. Weekend users, who generally have only used the bicycle once, are more likely recreational users.

Examining the length of each hire, it is difficult to determine separate effects associated with the frequency of use. Single users and multiple users both have similar patterns of usage in excess of 180 minutes. Single-trip users also show a fairly uniform distribution in shorter rental times as do multiple users.

Analysis of Sponsored Users

The OYBike system was used by 18 sponsored (nonfee paying) users. Sponsored users include local government employees as well as some members of the public. A total of 107 trips was made by sponsored users. Of these, 71 trips started and terminated at the same location.

Sponsored users clearly have a different pattern of daily usage than paying customers (Figure 11). Usage is greater during the week than on weekends, suggesting that most trips are not for leisure. While the time of day of most sponsored usage does not correspond to peak travel times, the length of trips tend to be much shorter than for fee-paying customers, again suggesting less leisure usage. The length of hire by most sponsored users was less than 15 minutes, although there were a substantial number in excess of 180 minutes (Figure 12).

Figure 11. Trips by Sponsored Users by Day of the Week

Figure 12. Length of Hire by Sponsored Users

Use by sponsored users peaked in September 2004 and declined throughout the autumn and winter with only a minor increase during spring and summer. Figure 13 plots this usage along with the maximum daily temperature. It is not known why sponsored usage did not pick up again in the spring and summer of 2005, but this may be partially due to less promotion of the system.

Figure 13. Trips by Sponsored Users and Maximum Daily Temperature

Examining daily weather conditions and how they affect sponsored users, we see one noticeable difference from the behavior of paid users. More sponsored users took trips on rainy days. About 60 percent of trips are on rainy days as shown in Figure 14 compared to only 30 percent for paid users. This suggests that sponsored-user trips were less likely to be leisure trips, but were perhaps either work related or for commuting, or were simply because of the free availability.

Sponsored users appear to be repeat users more frequently than fee-paying customers. Six sponsored users have used OYBike more than four times, or over one-third of all users (compared to only 5% of paid users making four or more trips).

Sponsored users used the system overwhelmingly on weekdays (Figure 15), with most bicycles hired during working hours, suggesting that these trips were taken for running errands from work or perhaps for work-related trips.

Figure 14. Daily Rainfall vs. Cumulative Percent of Total Sponsored Trips

Figure 15. Time of Hire and Weekday vs. Weekend Use by Sponsored Users

Conclusions

This evaluation assessed the potential of OYBike as a competitive mode of transport and identified opportunities for making the system work effectively. The analysis is constrained by the small amount of data available; however, there is enough evidence to tentatively support the conclusions that follow.

Analysis of the usage data and the survey data suggest that the primary market is for leisure trips. However, there is also potential for sponsored trips, subsidized by employers, which appear to be more utilitarian. The analysis is based mainly on conjecture regarding trip purposes from the time of day and on which days the trips occurred, with some supporting evidence from the trip purposes stated in the user survey.

The key potential of this particular smart bike system seems to be for leisure trips and recreational purposes. Therefore, finding ways to fully exploit this in terms of marketing and expansion is essential for future growth. Targeted initiatives aimed at recreational users would be beneficial. Also, placing locking stations at key recreational destinations might provide a way to connect public transport stations with recreational destinations and activities. One key issue is that, while London is potentially a very bicycle-accessible city, its road infrastructure, lack of good cycle lanes, and level of traffic are disincentives to widespread use. Despite this, cycle rates in London have increased in recent years (Transport for London 2004b).

Commute and utilitarian trips seem to have been taken primarily by the sponsored user group. One benefit is that these trips are clearly complementary to the leisure market. Sponsored users tended to use the bicycles on weekdays while paid users (who were primarily recreational consumers) used the system on weekends. Sponsored use appeared to be high when the system was originally made available in September 2004. However, while usage declined during winter months, there was no increase in usage by sponsored users to previous levels as the weather warmed. It is unclear why this was so, but it may suggest the need to engage with sponsored users and remind them of the benefits of using the system on a regular basis.

There was a clear pattern of seasonal usage. Both maximum temperature and rainfall totals had an effect on usage. This is not surprising as bicycle usage is a seasonal activity except for the most devoted cyclists. This does, of course, create problems for sustaining the system over many months of nonusage. OYBike reported that nonusage led to more maintenance problems with the gearing system.

Overall user satisfaction with the system was high. Key impediments to use are the uncertainty of the condition of the bicycles when they are checked out, the difficulty of using the locking system, and the need to use a mobile phone. Cost of using the system was not reported to be an issue. Many cited an interest in testing out the system, but it could not be determined whether this led to repeat usage. Most paid users used the system only once.

Most costumers used the system to replace public transport and walking trips. Although only a minor reduction in reported car trips was found, this is still a beneficial use of potential public resources if some people are diverted from using congested public transport systems. However, most reported usage occurred at nonpeak hours when public transport systems would not be congested. These sorts of effects are, of course, highly dependent on the location of the system. London conditions, such as the level of public transport usage, are fairly unique even in the UK.

Overall, while this system appears to be technically sound, future growth strategies should be geared toward a leisure market. Areas more frequently visited by tourists, with emphasis on sport sites for the London Olympics in 2012, might offer opportunities. Without substantial additional effort at attracting sponsored users, this part of the market will likely remain thin. This conclusion should, however, be taken with caution. First, the data was limited; and second, the specific location in which the pilot was conducted is only representative of a relatively densely populated, but not central, urban area. Potential may be higher within central business districts or conversely, less dense suburban areas (especially for egress from public transport stations). Further analysis of the many systems now being tested would be beneficial (DeMaio and Gifford 2004).

It is unlikely that this type of system could be financially independent of subsidy. The OYBike system was supported by grants from Transport for London and a charitable foundation. Like other systems of this type, OYBike was by no means financially self-supporting. Despite this, these types of systems may be a cheaper means of enhancing mobility than traditional public transport, even with low usage rates.

Acknowledgements

This research was funded by the SME Innovation Support Programme of the London Development Agency (LDA), part funded through the European Regional

Development Fund (ERDF), and focused on improving the competitiveness of London's Objective 2 businesses. The OYBike pilot program was partially funded by Transport for London and LBHF.

We would like to thank Martin Frost of the LDA, Simon Franklin of LBHF, and Bernie Hanning and Feroze Rub, the entrepreneurs behind the OYBike system.

The authors have no financial relationships with OYBike or any suppliers of technology to OYBike. In no way should this article be seen as an endorsement of OYBike or the specific technology used by OYBike.

References

- Ball, D., and A. Brooks. 2004. 2001 *Census report 2: Ethnic groups in Hammersmith & Fulham*. http://www.lbhf.gov.uk/Images/Part2_pages59-66_tcm21-20275.pdf, 62. Accessed 18 December 2005.
- DeMaio, P., and J. Gifford. 2004. Will smart bikes succeed as public transportation in the United States? *Journal of Public Transportation* 7(2): 1–15.
- Greater London Authority. 2001. *The mayor's transport strategy*. http://www.london.gov.uk/approot/mayor/strategies/transport/trans_strat.jsp. Accessed 18 December 2005.
- Transport for London. 2004a. Transport for London annual report. http://www.tfl.gov.uk/tfl/about/report-library/annual-reports/2004/annual_report_2004.shtml. Accessed 18 December 2005.
- Transport for London. 2004b. *Creating a chain reaction: The London cycling action plan*. <http://www.tfl.gov.uk/cycles/downloads/reports/cycling-action-plan.pdf>. Accessed 18 December 2005.

About the Authors

ROBERT NOLAND (r.noland@imperial.ac.uk) is a reader in transport and environmental policy and heads the Environment and Policy Research Group within the Centre for Transport Studies at Imperial College London. He received a Ph.D. in energy management and environmental policy from the University of Pennsylvania. Prior to joining Imperial College, Dr. Noland was a policy analyst at the U.S. Environmental Protection Agency and also conducted post-doctoral research in the

Economics Department at the University of California at Irvine. His research focuses on the impacts of transport policy and behavior on environmental outcomes. This is defined very broadly to include not just air and water quality impacts, but also impacts on safety, climate, health, and other factors associated with overall quality of life.

MUHAMMAD ISHAQUE (moazzam.ishaque@jacobs.com) is a Transport Planner at Jacobs Ltd. He has recently received his Ph.D. from the Centre for Transport Studies, Imperial College London. His research interests include nonmotorized transport and how current traffic control policies affect pedestrians and bicyclists.

Development, Evaluation, and Selection of Advanced Transit Signal Priority Concept Directions

*Amer Shalaby and Jinwoo Lee, University of Toronto
John Greenough and Stanley Hung, LEA Consulting Ltd.
Michael D. Bowie, Fortran Traffic Systems*

Abstract

This article presents a process to define the framework for an advanced Transit Signal Priority (TSP) algorithm. For this study, traffic and transit agencies from a broad range of municipalities in Ontario, Canada, provided their views and expertise on various TSP-related issues, including practical needs, design implementation, performance measures, and challenges in developing effective TSP control systems. Based on their inputs as well as the objectives of the project, a set of TSP control concept directions was developed that are characterized with different methodologies and technologies. A listing of selection criteria was also established to evaluate the proposed TSP concept directions. Using these criteria, a ranking and evaluation process was undertaken to select one final TSP control concept that is of interest to potential users of advanced TSP systems. The work described in this article provides a successful example of a process to build consensus among stakeholders for advancing TSP developments.

Introduction

In September 2001, Transport Canada announced a commitment and solicited proposals for the development of products and services that will accelerate the

growth of ITS knowledge and skills, and promote the uptake and commercialization of ITS technology in Canada. A joint team from the University of Toronto, LEA Consulting Ltd., and Fortran Traffic Systems was awarded a contract for the development of an advanced Transit Signal Priority (TSP) algorithm, which has the potential to be deployed in the field. The objectives of this project can be summarized as follows:

- Develop and evaluate a unique, innovative TSP algorithm, that has the potential to be deployed in the field.
- Facilitate the exchange of knowledge and ideas between the academic research community and the industrial sector during the algorithm development process.
- Provide a means to improve mobility and transportation efficiency.
- Increase operational and regulatory efficiencies for system users and public agencies.
- Encourage the development of products and services that will accelerate the growth of ITS knowledge and skills, and promote the uptake and commercialization of ITS technology.

This article presents a process to develop the framework of the advanced TSP control algorithm as well as the rationale for the selected algorithm approach, rather than describing the developed algorithm itself. Details of the final products of this research can be found elsewhere (Lee et al. 2005, 2006). This article presents various types of TSP control concepts that are characterized with different methodological and technological components. The design of these multilevel TSP concept directions was based on progressive levels of control concepts for the provision of sophisticated TSP control. This research also provides various TSP-related issues from the perspectives of traffic and transit agencies. Professionals from a broad range of municipalities in Ontario, Canada, representing traffic and transit departments, offered their views and expertise on various TSP-related issues, including practical needs, design implementation, performance measures, and the challenges of developing advanced TSP systems. The work described here provides an example of a process to build consensus among stakeholders for advancing TSP developments.

Historical background of TSP is briefly presented in the next section. The cornerstone of most proposed TSP control concepts involves an accurate transit travel time prediction method to support the achievement of more efficient and effec-

tive signal priority for both transit and traffic. The state-of-the-art in the transit travel time prediction methods is provided next. Following that is a detailed description of the proposed set of TSP control concepts, the used evaluation criteria, and the selection process.

Background

TSP Measures

TSP is a signal control strategy that provides preferential treatments to transit vehicles at signalized intersections. Of the various ITS technologies, TSP offers one of the most cost-effective approaches to enhance the effectiveness and efficiency of transit operations. This concept of providing favorable treatments to transit vehicles has evolved since the 1970s through a number of installations in North America and Europe (Evans and Skiles 1970; Courage and Wallace 1977). Early implementations of TSP systems were found inefficient mainly due to the negative impacts on automobiles and on the existing traffic signal operation. Recently, however, several developments were achieved to meet the increasing demand by many agencies for effective TSP operation in response to the growing traffic congestion and its adverse impacts on transit operation. TSP treatments can be classified into four types, which also roughly represent the evolution of TSP and its level of sophistication over the years (Shalaby and Hemily 2004). These types are described briefly below.

Passive Priority. This treatment refers to the very initial methods of TSP, which simply provide adjusted signal timing to accommodate the slower travel speed of transit vehicles due to dynamic characteristics of heavy vehicles as well as the dwell time incurred at stops. Resetting signal coordination plans based on transit travel time, splitting, or the increasing priority phase are typical passive TSP schemes (Wood and Baker 1992). The great advantages of passive priority methods are their relatively low-cost and ease of implementation and operation, since transit detection or communication equipment required to detect the presence of transit vehicles are not necessary. Passive priority becomes most effective with high transit vehicle frequencies, predictable transit travel times, and overall light or moderate traffic volumes (Vincent et al. 1978). However, passive priority may result in unnecessarily significant delays to nontransit vehicles particularly where traffic demand is heavy, since it operates preferential signal timings for transit vehicles even when buses are not present.

Active Priority. Active priority addresses the critical shortcomings of passive priority by adopting technologies that selectively detect transit vehicles and communicate this information to the traffic controller. Under this scheme, signal priority is given only when transit vehicles are approaching intersections. Typical active priority systems comprise a transit vehicle sensor located upstream of an intersection approach that requests signal priority, a downstream sensor at the intersection stopline that cancels the priority call, and a signal controller. When a transit vehicle is between the upstream and the downstream sensors, the signal controller provides the designated TSP strategies for predetermined durations. Among the various active priority strategies, green extension of the transit phase and early truncation of the nontransit phase are the most widely implemented schemes. Previous studies investigated the efficiency of the various active priority strategies through field tests and the simulation analyses (Ludwick 1975; Benevelli et al. 1983; Boje and Nookala 1996). Active priority has been successful in speeding up transit vehicles along arterial corridors. However, in some instances, transit vehicles may be granted priority when not needed (e.g., vehicle is ahead of schedule or carrying few passengers), resulting in significant delays to nonpriority traffic.

Conditional Active Priority. Recent advances in Intelligent Transportation Systems (ITS) have provided more capabilities to support sophisticated TSP control. Conditional TSP grants priority selectively to transit vehicles that meet certain conditions based on deviation of the vehicle from the schedule or time elapsed since last awarded priority. Conditional TSP requires additional mechanisms for measuring whether the approaching vehicle meets the criteria for granting priority. These may involve an Automated Vehicle Location (AVL) system for measuring schedule adherence and possibly in the future reliable Automated Passenger Counter (APC) systems for measuring transit vehicle occupancy. Recently, conditional active priority has been implemented in several cities (Fehon et al. 2004; Kimpel et al. 2004). Conditional TSP has the potential of limiting buses running ahead of schedule and of mitigating the impacts of unconditional TSP on nonpriority traffic.

Adaptive Priority. Adaptive TSP control refers to a relatively new generation of priority schemes, which seeks to achieve advanced operational objectives by means of adaptive signal control. Examples of operational objectives include improving transit headway regularity, reducing total vehicle delay in the corridor, and maximizing person throughput. Under adaptive TSP, the traffic signal controller adjusts its plan dynamically according to the criteria reflecting the desired objective. Adaptive control often requires feedback of frequently updated traffic and/or

transit location data into the procedure of signal control adjustment for a better adaptation of rapidly changing traffic and transit situations. Adaptive priority control offers considerable promise for maximizing benefits for both transit vehicles and the general traffic, but the strategy has been only evaluated in laboratory environments and is still in the development stage (Ling and Shalaby 2004; Chang et al. 1998; Conrad et al. 1998).

Transit Travel Time Prediction Models

The prediction of transit travel times is a critical element in many Advanced Public Transportation System (APTS) applications including Bus Information System (BIS). Many studies have modelled traffic conditions and travel times for automobiles, but only a few have focused on transit travel time prediction. Previous transit arrival prediction efforts are classified into three types according to their adopted techniques, including regression models, Kalman filtering, and neural networks.

Regression Models. As conventional modelling approaches, both linear and non-linear regression models have been preferably used for transit arrival time prediction because of their relative ease to develop and because they are well suited for parameter estimation problems. Abkowitz and Engelstien (1998) developed two regression-based models to predict mean running time and running time deviation. Some parameters representing the physical bus route characteristics and others representing the dynamic route characteristics were included in the mean running time model, while the running time deviation model was developed in relation to link length and previous running time. Abdelfattah and Khan (1998) also conducted a similar study but the test results of the developed model showed relatively large deviations between the predicted and the actual arrival times.

Kalman Filtering Models. Kalman filtering is a statistical time-series approach, which evolved from state-space representations in linear control theory. Kalman filtering models have relative advantage over other methods in that time-dependent parameters can be included in the model. Wall and Dailey (1999) proposed a Kalman filtering-based transit location tracking model using data obtained from AVL systems. Shalaby and Farhan (2004) demonstrated a Kalman filtering-based dynamic transit travel time prediction model using real-time AVL and APC data. The proposed Kalman filtering model outperformed neural networks and regression models in the simulation analysis.

Artificial Neural Network Models. Artificial Neural Networks (ANNs) have been applied to an increasing numbers of transportation applications over the past

years. ANNs reproduce the structure and functioning of the brain to mimic its learning capability, which is based on the modification of the connection weight between output and input data. Unlike linear regression methods, ANNs can capture nonlinear relationships between explanatory variables and dependent variables appropriately. Both the studies by Chien et al. (2002) and Kalaputapu and Demetsky (1995) include examples of ANN-based transit arrival prediction models and showed promising test results.

Simulation Models

Simulation models are very effective tools for analyzing the performance of transportation systems. Real-world systems include interactions among various components, which are very complicated and simultaneously changing, and mathematical modelling approaches are often found inadequate to represent such systems. Simulation models mimic the complicated behavior of systems and provide demonstrations of how those systems are likely to perform. Although simulation models can describe a wide variety of dynamic problems in reality, the applications of simulation have been limited only to off-line applications including analysis, evaluation, and design purposes, mainly due to concerns about the processing time in on-line applications. However, with recent advancements in processing technologies, several studies have adopted on-line simulation modeling for the purposes of traffic prediction (Kosonen and Bargiela 2000) and control (Kosonen 2003). Both studies demonstrated the potential for on-line applications of simulation models. Recently, on-line simulation models for the prediction of transit travel time have been developed for the specific application to TSP (Lee et al. 2005, 2006).

TSP Control Concept Directions

Development of the Candidate TSP Control Concepts

To assist the project team in defining a concept direction for an advanced TSP algorithm, a technical advisory group was formed. The group provided technical input throughout the design process, and assisted in the development of concept directions and the final product. The project team invited professionals from a broad range of municipalities in Ontario, Canada, representing traffic and transit agencies that are already operating a TSP program, currently designing a TSP program, or having an interest in creating a TSP program. The strength and benefit of the technical advisory group stemmed from the expertise of some members

who have operational TSP deployment experience, which could identify and help address real design and operating issues, and who could provide suggestions on potential improvements in TSP operations. Representatives from agencies without current TSP deployments would also provide important input on the needs and features of desired TSP systems for their agencies. The advisory group's composition was generally well balanced between traffic and transit representation. A total of 23 representatives from 10 transit agencies and 13 traffic agencies participated in the project working sessions. Advisory group members were asked about potential issues in TSP from the traffic and transit perspectives. See Table 1 for a summary of their responses.

Table 1. TSP Issues in Traffic and Transit Perspectives

The project team developed a set of multilevel TSP concept approaches based on the collected feedback and also on a literature review of TSP control. The candidate TSP concept approaches are characterized by different methodological and technological components. A higher level TSP concept has the ability to provide more sophisticated TSP control but requires more technologies and equipment than a lower level concept. This multilevel approach design enables the system to built up gradually and to offer varying degrees of TSP control, depending on

the characteristics of transit and traffic operations. Eight concept directions were developed based on the following assumptions:

- should represent a wide range of possible advancements to active TSP
- should employ an incremental approach to advancement
- assume medium to high frequency service, main transit route, and near-side stops

Figure 1 shows the range of concept directions, while Table 2 provides more details on each concept. The differentiating elements between the concept directions are mainly related to the type of technologies and methodologies used and application context (i.e., single intersection or multiple intersections).

Figure 1. TSP Concept Directions

As shown in Table 2, the developed TSP concept directions include the typical active TSP control method as the most fundamental concept direction, Level I-1, progressing to the transit route-level TSP control as the highest concept (Level III-1). Detailed descriptions about the TSP control methods and relative advantages and limitations follow.

Level I-1. The Level I-1 concept direction provides unconditional TSP control using operation rules, which define a “decision point” and TSP strategies. The signal controller actuates TSP strategies, such as green extension and red truncation, at a decision point in the signal cycle if priority is requested. All approaching transit vehicles can request signal priority under operation of this TSP concept. This con-

Table 2. TSP Concept Directions

cept direction requires only simple control logic and inexpensive equipment, and has the ability to reduce transit signal delay. However, it also may result in ineffective TSP control, negative impacts on side-street traffic, and unreliable transit service by granting signal priority to transit vehicles even running ahead of schedule.

Level I-2. Level I-2 adopts an improved TSP control rule. The signal controller decides whether to provide signal priority depending on the average transit vehicle arrival time in the signal cycle and the average transit travel time to the stopline. For instance, the controller does not grant the green extension strategy if the detected vehicle is not expected to travel through the intersection by the end of the extended transit phase. This concept direction has a relative advantage compared to Level I-1 by reducing the frequency of signal timing modifications, and consequently lessening negative impacts on side-street traffic. However, the variability in transit travel time may lead to inefficient TSP control particularly where the traffic conditions change unexpectedly and rapidly.

Level I-3. This concept direction builds on Level I-2 by employing AVL and/or APC equipment to provide conditional signal priority based on the actual headway and/or occupancy of the approaching transit vehicle. Using historical and current AVL data, this concept direction may adopt a *simple* transit travel time prediction model (e.g., regression). This control concept may avoid providing signal priority to transit vehicles that are ahead of schedule or with low occupancies. More accurate transit travel time prediction also may improve the TSP control efficiency (Koonce et al. 2002). However, this concept direction is still insensitive to the actual traffic conditions, leading to some instances of inefficient applications of TSP strategies. The TSP control in this level (and all Level I concepts) focuses only on transit vehicles at individual intersections. Traffic conditions along cross streets are not considered in all Level I-type concepts.

Level II-1. The distinct difference between Level I and Level II concepts lies in the dynamic transit travel time prediction using real-time traffic and transit sensor data. This enhancement enables the signal controller to operate more TSP strategies such as transit phase early truncation, which demands a high degree of prediction accuracy. Dynamic TSP control methods would select the most appropriate TSP strategy among a number of strategies based on the prediction result. This approach is expected to reduce significantly instances of ineffective operation of TSP strategies bringing about considerable transit delay reduction as well. The Level II-1 concept employs advanced transit prediction as well as dynamic TSP control as the methodological components. Since this TSP concept does not employ side-street traffic sensors or the AVL system, the TSP control in this level provides unconditional signal priority regardless of transit schedule adherence or side-street traffic conditions.

Level II-2. The Level II-2 concept direction further improves the previous strategy by employing traffic sensors in cross-street approaches. The signal controller has the ability to consider explicitly the side-street traffic condition using the traffic count data or simple traffic flow model when it decides whether to provide TSP strategies. Some threshold values in terms of side-street traffic delay may be defined for the conditional TSP control. The collected traffic sensor data also can be used for different purposes (e.g., to establish traffic operation or management plan). Compared to the more advanced TSP control concepts (i.e., Level II-3, II-4, and III-1), this level of TSP control also does not consider transit vehicles running ahead of schedule and/or that are empty.

Level II-3. The Level II-3 concept, similar to the Level I-3 concept, uses AVL and/or APC equipment for the transit headway and/or occupancy-based conditional TSP control. However, real-time AVL data also can be used to calibrate the prediction result or to update the transit travel times as the detected transit vehicle approaches the stopline (Lee et al. 2006). Under the operation of this control concept, provision of TSP is conditional on cross-street traffic conditions, schedule adherence, and passenger occupancy. Using transit vehicle location real-time information, this level can obtain improved prediction accuracy. However, it does not necessarily achieve an optimal solution with regard to delay reduction and minimization of impacts. This limitation also applies to all previous concepts that employ a rule-based TSP control method.

Level II-4. The Level II-4 concept direction attempts to find optimal traffic signal timings for both transit and traffic rather than overriding the normal traffic signal with a predefined TSP strategy. A dynamic optimization tool is required such as Genetic Algorithms or Dynamic Programming. Using real-time transit location information and traffic sensor data, the signal controller continuously adjusts the traffic signal timing plan. In fact, this level of TSP control concept works in a similar way to adaptive traffic signal control systems (Robertson and Hunt 1991; Mirchandani and Head 2001; Gartner et al. 2002), except that the transit vehicles are separately considered in the optimization process. The Level II-4 concept offers several advantages over other rule-based signal priority control methods. First, to operate TSP strategies, several parameters (i.e., TSP running signal phases, maximum extension phase length, truncation phase length, etc.) must be predefined for each TSP-operating intersection. The optimization-based TSP control does not need to define such TSP control rules for the optimal TSP operation. Second, in the optimization process, weighting factors can be given to transit and traffic based on a control policy. For instance, more weight can be given to transit vehicle optimization if the control policy is to minimize transit signal delay while maintaining the traffic delay at some level (e.g., during nonpeak time periods). Finally, offset recovery can be operated with more flexibility under the optimization-based control by assigning more signal times to more congested link approaches.

Level III-1. The highest Level III-1 concept expands the application scope of TSP control to transit route or multiintersections. In this level of concept direction, transit vehicle arrival information in the upstream or further intersection link approaches is indicated to downstream intersections through control center or peer-to-peer communications. Downstream signal controllers gradually modify

traffic signal timing in advance of actual transit vehicle arrival. This prior signal action provides the desired signal phase on transit vehicle arrival and also reduces the negative impacts of sudden traffic signal timing change on other traffic. For this highly sophisticated TSP control, a transit detection system along the transit route is required as well as a long-range transit travel time prediction model. The limitation of this highest level of TSP control lies in the complexities of the required TSP operation software.

Identifying the TSP Concept Evaluation Criteria

An evaluation method identified the concept directions that are of interest to the stakeholders (e.g., transit service providers, transit users, traffic system operators, and automobile drivers) involved in TSP control. The project team presented the developed TSP concept directions to members of the technical advisory group in a working session. Several questions were posed to the advisory group to identify concept selection criteria that could be used to gauge the relative importance of each concept direction in relation to what is effective and achievable. Table 3 presents responses to the interview questions.

The comments made by each group were recorded and retained by the project team for further consolidation and assessment. The comments would lead to the evaluation and selection of a short list of TSP concept direction candidates for further refinement and evaluation. With the comments and feedback gathered from the working session with the advisory group members, the team reorganized the information into a list of evaluation criteria (see Table 4).

Selection of Viable TSP Concept Directions

A two-phase ranking methodology was used based on the primary criteria identified by the technical advisory group members as well as the project team. In the first phase of the evaluation, the concepts were ranked, independent of each other, according to the defined criteria. The ranking scale used for this task ranged from 1 to 3; where a value of 1 represented a weak association to the criterion, and a value of 3 represented a high association. Under some criteria it was necessary to use half points to more discretely distinguish between the various concept directions.

In the second phase of the evaluation, each criteria was ranked, independent of each other, according to the general importance of the noted criterion. A ranking scale with values between 1 and 3 was also used; where a value of 1 represented a weaker importance, while a value of 3 represented a greater importance. Values assigned were then multiplied with the respective values determined in phase one

Table 3. Summary of Responses to Interview Questions

The comments made by each group were recorded and retained by the project team for further consolidation and assessment. The comments would lead to the evaluation and selection of a short list of TSP concept direction candidates for further refinement and evaluation. With the comments and feedback gathered from the working session with the advisory group members, the team reorganized the information into a list of evaluation criteria (see Table 4).

Table 4. Evaluation Criteria and Factored Ratings

of the evaluation for each concept direction and criteria. The team undertook the ranking and evaluation exercise; the results are shown in Table 5.

Based on this evaluation methodology and the results, it was recommended that the top three ranking concept directions, Levels II-3, II-1, and II-2, be rationalized further through the preliminary design phase of the project.

Preliminary TSP Algorithm Design

The purpose of the preliminary algorithm design was to further elaborate the definitions and designs of the selected TSP control concepts to help inform the final concept selection process. As part of the preliminary algorithm design phase

Table 5. Evaluation and Ranking of TSP Concept Directions

of this project, the three top-ranked concept directions were further rationalized, developed, and detailed through an additional working session with the technical advisory group. The intent of this work was to provide further thought and consideration on how the concepts could be physically installed, operated, and controlled. Through this derivation effort, the TSP concepts were discussed in greater detail to settle on a final concept direction to be developed through a detailed design process and eventually tested in a microsimulation environment.

Level II-1 Concept Design. Figure 2 illustrates the system configuration for the concept Level II-1.

- Transit vehicles are equipped with TSP signal transmitters that are always active.
- TSP detectors, or detection points, are located at the link upstream and the stopline.
- Traffic detectors are located up and down stream along the transit route to measure traffic volumes, speed, and occupancy; data are relayed to the traffic signal controller.
- Traffic signal controller will assess the data through a travel time prediction model with real-time transit travel time and traffic data as inputs.
- TSP strategies are initiated by the traffic signal controller based on the predicted transit vehicle travel time through a rule-based algorithm.
- TSP sequence will be unconditionally provided.
- Traffic signal controller would issue a signal timing recovery plan after the TSP call is dropped or maxed out.

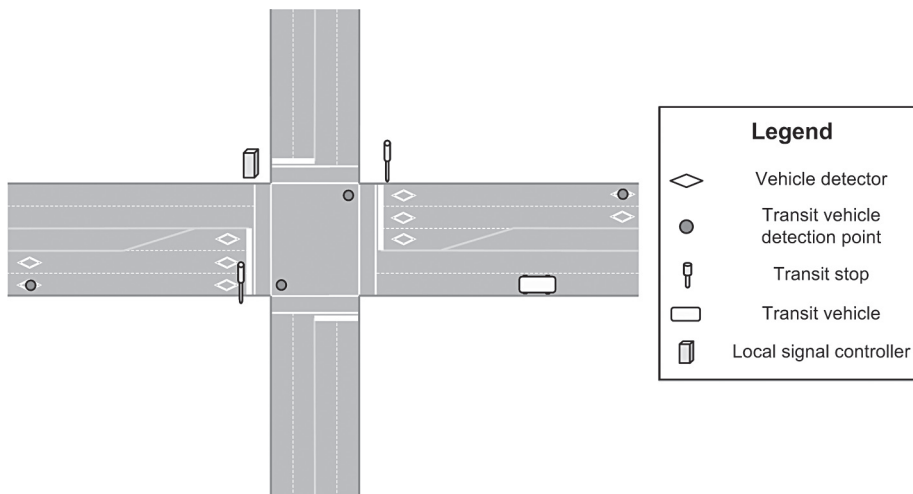


Figure 2. Level II-1 Concept Configuration

Level II-2 Concept Design. The system configuration for the Level II-2 concept direction is given in Figure 3.

- Transit vehicles are equipped with TSP emitters that are always active.
- Traffic detectors are located up and down stream along the transit route and also in the cross- street approaches to measure traffic volumes, speed, and occupancy; data are relayed to the traffic signal controller.
- Implementation of the TSP strategy will be conditional based on the overall effect on cross-street traffic.
- TSP strategies are initiated by the traffic signal controller based on the predicted transit vehicle travel time through a dynamic rule-based algorithm.
- Traffic signal controller would issue a signal timing recovery plan after the TSP call is dropped or maxed out.

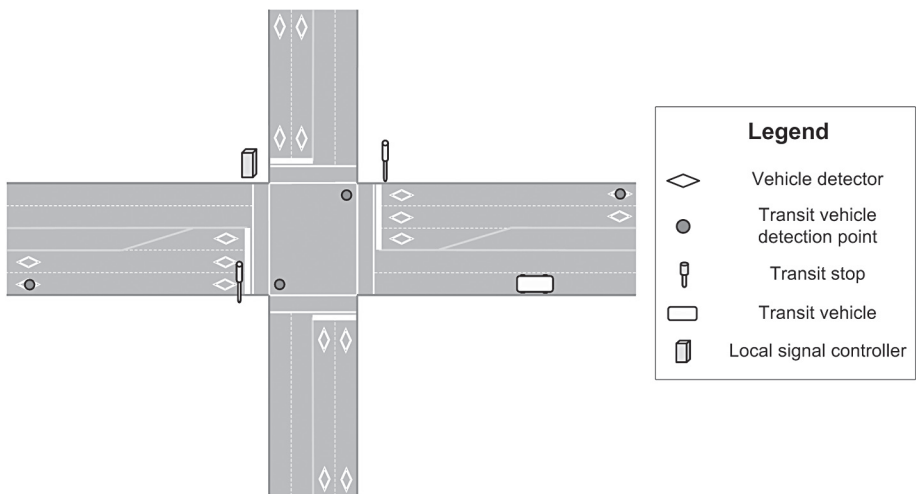


Figure 3. Level II-2 Concept Configuration

Level II-3 Concept Design. Figure 4 depicts the Level II-3 concept configuration.

- Transit vehicles are equipped with an intelligent computational device such as vehicle logic unit (VLU).
- On-board AVL system provides VLU with real-time position data.

- VLU determines if TSP is required through a rule-based algorithm associating schedule adherence and/or vehicle occupancy.
- Traffic signal controller determines the predicted travel time through AVL-gathered data; prediction model could also reference historical route travel data.
- If the VLU determines that a TSP call is warranted to maintain the transit schedule, the TSP emitter would be activated at the desired point along the route.
- Traffic detectors are located up and down stream along the transit route and in the cross-street approaches to measure traffic volumes, speed, and occupancy; data are relayed to the traffic signal controller.
- Traffic signal controller will assess the data through a travel time prediction model with real-time AVL transit travel time and traffic data from all approaches as inputs.
- Traffic signal controller continuously updates the predicted arrival time of the transit vehicle.
- Implementation of the TSP strategy will be conditional based on the overall effect on cross-street traffic.
- TSP strategies are initiated by the traffic signal controller based on the predicted transit vehicle arrival time through a rule-based algorithm.
- Traffic signal controller would issue a signal timing recovery plan after the TSP call is dropped or maxed out.

Figure 4. Level II-3 Concept Configuration

Selection of the Final TSP Concept Direction

The preliminary designs of the three short-listed concept directions were presented to the technical advisory group, and feedback was solicited. Most members responded that the selected concept directions were within their expectations, and provided some recommendations related to further development.

- In selecting the final concept, the required policies, functionality, and g/C ratios should be taken into consideration.
- The validity of the concept (i.e., ability to monitor the performance) should be addressed.
- Complex systems are not necessarily good for small municipalities. Can the costs be justified?
- Criteria for the deployment of each concept must be developed and defined. Where and when could the concept be used?
- Clear public policy objectives must be identified.

Based on the preliminary designs and on the additional feedback received from the technical advisory group, the project team discussed which of the preferred concept directions to move forward into detailed design, modelling, simulation, and evaluation as a prototype of an advanced TSP algorithm. From a technical standpoint, the project team determined that design and deployment barriers associated with any of the three selected concepts are manageable. Each of the concepts is also an improvement on the status quo deployment and operation of TSP. Therefore, there is no underlying benefit to select one concept over another from a technical outlook.

In considering the three concept directions from a practical deployment perspective, discussion was raised regarding the feasibility of deploying side-street traffic sensors at all intersections. This is surely not a feasible consideration, especially at intersections with low side-street traffic volumes and operating at a good level of service. Therefore, the need for a traffic sensor on the side street should be considered in greater detail (i.e., cost/benefit assessments) during the design phase for each intersection. At the conclusion of the selection process, the team resolved to design and model a variation of the concept direction Level II-3. The variation would exclude the side-street traffic detectors, so the final concept direction does not provide side-street conditional TSP control, while keeping the other features of the Level II-3 concepts. The detailed description of the development of the final

control concept together with the evaluation results are available elsewhere (Lee et al. 2005, 2006).

Summary

This article presents an approach to develop a framework for advanced TSP control algorithms. A full range of TSP concept directions, which are defined on the basis of the most critical factors and features, are provided in the research. For this study, traffic and transit agencies from a broad range of municipalities in Ontario, Canada, provided their views and expertise on various TSP-related issues including practical needs, design implementation, performance measures, and challenges in developing effective TSP systems. Based on the technical inputs, the project team developed a multilevel framework for TSP concept directions that provide different levels of sophistication for TSP control. Three TSP control concepts were selected for further development following an evaluation and ranking process. All of the selected concept directions included a component of transit travel time prediction, which certainly indicates the demand for more efficient TSP control method. Further detailed design and configuration information were prepared and presented to the technical advisory group members for the selection of the final TSP control concept. Based on the additional feedback received from the technical advisory group and the feasibility of deployment, the Level II-3 concept direction with a minor variation was selected as a prototype of an advanced TSP control algorithm. Detailed information about the developed advanced TSP control algorithm can be found elsewhere (Lee et al. 2005, 2006). Finally, the work described in this article provides a successful example of a process to build consensus among stakeholders for advancing TSP developments.

Acknowledgment

This research has been supported by Transport Canada under the ITS R&D program.

References

Abkowitz, M. D., and I. Engelstien. 1983. Factors affecting running time on transit routes. *Transportation Research* 17A (2): 107–113.

- Abdelfattah, A. M., and A. M. Khan. 1998. Models for predicting bus delay. *Transportation Research Record* 1623: 8–15.
- Benevelli, D. A., A. E. Radwan, and J. W. Hurley. 1983. Evaluation of a bus preemption strategy by use of computer simulation. *Transportation Research Record* 906: 60–67.
- Boje, B.F., and M. Nookala. 1996. Signal priority for buses: An operational test at Louisiana Avenue, Minneapolis. *Compendium of Technical Papers for the 66th ITE Annual Meeting*. Washington DC: 309–313.
- Chang, G. L, M. Vasudeva, and C. C. Su. 1998. Bus preemption under adaptive signal control environments. *Transportation Research Record* 1494: 146–154.
- Chien, S. I., Y. Ding and C. Wei. 2002. Dynamic bus arrival time prediction with artificial neural networks. *Journal of Transportation Engineering* 128 (5): 429–438.
- Conrad, M., F. Dion, and S. Yagar. 1998. Real-time traffic signal optimization with transit signal priority. *Transportation Research Record* 1634.
- Courage, K. G., and C. E. Wallace. 1977. Evaluation of some bus priority strategies on NW 7th Avenue in Miami. *Transportation Research Record*. 626: 32–35.
- Evans, H., and G. and Skiles. 1970. Improving public transit through bus preemption of traffic signals. *Traffic Quarterly* 24 (4): 531–543.
- Fehon, K., J. Jarzab, C. Emoto, and D. Dagang. 2004. *Transit signal priority for Silicon Valley bus rapid transit*. DKS Associates, <http://www.dksassociates.com/>, Accessed July.
- Gartner, N. H., F. J. Pooran, and C. M. Andrews. 2002. Optimized policies for adaptive control strategy in real-time traffic adaptive control systems: Implementation and field testing. *Transportation Research Record* 1811: 148–156.
- Kalaputapu, R., and M. Demetsky. 1995. Modeling schedule deviations of buses using AVL data and artificial neural networks. *Transportation Research Record* 1497: 44–52.
- Koonce P., J. Ringert, T. Urbanik, W. Rotich, and B. Kloos. 2002. Detection range setting methodology for signal priority. *Journal of Public Transportation* 5 (2): 113–136.

- Kosonen, I., and A. Bargiela. 2000. *Simulation-based traffic information system*. 7th World Congress on Intelligent Transport Systems. Turin, Italy.
- Kosonen, I., 2003. Multi-agent fuzzy signal control based on real-time simulation. *Transportation Research* 11C: 389–403
- Kimpel, T. J., J. Strathman, R. Bertini, P. Bender, and S. Callas. 2004. *Analysis of transit signal priority using archived TriMet bus dispatch system data*. 83rd Annual Meeting of the Transportation Research Board, Washington, DC.
- Lee, J., B. Shalaby, J. Greenough, M. Bowie, and S. Hung. 2005. Advanced transit signal priority control using on-line microsimulation-based transit prediction model. *Transportation Research Record* 1925: 185–194.
- Lee, J., A. Shalaby, J. Greenough, M. Bowie, and S. Hung. 2006. *TSP-advance: An advanced transit signal priority system—Development and evaluation*. 85th Transportation Research Board Annual Meeting, Transportation Research Board, National Research Council, Washington, DC.
- Ling, K., and A. Shalaby. 2004. Automated transit headway control via adaptive signal priority. Special Issue on Modeling for Transit Operations and Service Planning, *Journal of Advanced Transportation* 38 (1): 45–67.
- Ludwick, J. S. 1975. Simulation of an unconditional preemption bus priority system. *Transportation Research Record* 906: 1–10.
- Mirchandani, P., and L. Head. 2001. A real-time traffic signal control system: Architecture, algorithms, and analysis. *Transportation Research* 9C: 415–432.
- Robertson, D. I., and P. B. Hunt. 1991. Optimizing networks of traffic signals in real time—The SCOOT method. *IEEE Transactions on Vehicular Technology* 40 (1).
- Shalaby, A., and A. Farhan. 2004. Prediction model of bus arrival and departure time using AVL and APC data. *Journal of Public Transportation* 7 (1): 41–61.
- Shalaby, A., and B. Hemily. 2004. *Urban public transit ITS research and development in Canada*. Work Group 1.3, ATLANTIC Project.
- Vincent, R. A., B. R. Coope, and K. Wood. 1978. *Bus-actuated signal control at isolated intersections*. Report 814. Crowthorne, UK: Transportation and Road Research Laboratory.

Wall, Z., and D. J. Dailey. 1999. *An algorithm for predicting the arrival time of mass transit vehicle using automatic vehicle location data*. 78rd Annual Meeting of the Transportation Research Board, Washington, DC.

Wood, K., and R. T. Baker. 1992. Using SCOOT weightings to benefits strategic routes. *Traffic Engineering and Control*: 226–235.

About the Authors

AMER SHALABY (amer@ecf.utoronto.ca) received his master's and Ph.D. degrees from the Department of Civil Engineering, University of Toronto in 1991 and 1997, respectively. He was a postdoctoral fellow at the university's Joint Program of Transportation in 1996–1997 and an NSERC Industrial Research Fellow at IBI Group in 1997–1998. From 1998–2000, he was an assistant professor at Ryerson University, where he also directed the Vehicle Safety Research Centre. Since January 2001, Dr. Shalaby has been an assistant professor at the University of Toronto. His research specialty is in the area of ITS, with emphasis on transit applications. His research interests also include strategic and service planning of public transit systems.

JINWOO LEE (leeji@ecf.utoronto.ca) is a Ph.D. student and a graduate student researcher in the Department of Civil Engineering at the University of Toronto. His research areas of interest include traffic signal control, transit signal priority, and ITS applications. Mr. Lee is also a member of the Transportation Systems Group of LEA Consulting Ltd., providing his technical expertise on various traffic engineering and ITS-related projects.

JOHN GREENOUGH (jgreenough@LEA.ca) is vice president of LEA Consulting Ltd., Markham, Ontario, and is also head of LEA's Transportation Systems Group. For more than 25 years, Mr. Greenough has been deeply involved in the planning, design, deployment, and operations of many ITS installations across Canada and in the United States, with focus on advanced traffic signal control systems, freeway and corridor traffic management systems, advanced transit management systems, including TSP, as well as transportation infrastructure security design services. For nearly a decade, he was a manager of Traffic Systems for the former Metropolitan Toronto, where he directed significant advancements in TSP, along with a complete modernization of much of Toronto's traffic systems.

MICHAEL D. BOWIE (*mbowie@fortrantraffic.com*), who was introduced to the traffic control industry in 1967 with Canadian General Electric, has been involved with the design, production, installation, maintenance, and training of numerous ITS products including traffic controllers, video incident detection, and central computer systems. In his current position as manager of Business Development, Mr. Bowie is instrumental in defining customer requirements in the continued product development of Fortran's Fastracs Traffic Management System. These requirements include areas such as TSP, light rail transit preemption and advanced video management systems for incident detection and data collection.

STANLEY HUNG (*shung@LEA.ca*) is a member of the Transportation Systems Group of LEA Consulting Ltd. He has been involved with several TSP and traffic signal control related projects. In respect to state-of-the-art development of TSP, Mr. Hung was part of the project team for the research and development of an advanced TSP algorithm with Transport Canada. Mr. Hung has provided his expertise for the deployment of TSP in the City of Peterborough, the Regional Municipality of York, the City of Edmonton, the City of Brampton, and the City of Toronto.